INL/RPT-22-69378

Irrigation Modernization Task 4: Accelerating Energy Solutions

September 2022

FY2022 Final Report

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EXECUTIVE SUMMARY

This report offers insights on energy solutions for irrigation modernization that serve the needs of farmers as well as residents and industry in the local community. Solutions are found in the irrigation districts where local generation from renewable energy sources – solar, hydro, and wind – can be combined with energy storage and customer loads. These combined resources configured in microgrids can lower costs during peak loads and provide resiliency by maintaining electricity supply during outages. The goal of this project, as stated in the FY2022 AOP, is to promote realization of energy solutions that are tailored to physical location, community, infrastructure, and energy value streams. Further, the goal is to develop examples of how to increase the value of, and overcome barriers to, energy solutions in the context of irrigation modernization. In pursuit of that goal, the project looked at options for:

1) Reducing the cost of energy consumed in irrigation systems,
2) Increasing the revenue from surplus power generation, and
3) Deploying new power generation configured as part of a local microgrid.

Potential solutions to reducing energy costs and increasing surplus power revenue revolve around addressing regulatory and legal constraints tied to how power is allocated and purchased and sold by utilities. Some headway was made in identifying barriers and ways to push utilities to be more accommodating to distributed energy sources; however, for the most part, real progress hinges on changes at the regulatory and legislative level.

Deployment of local, renewable generation systems can be implemented provided the economics of the project and the location are favorable. In concert with Famers Conservation Alliance and Energy Trust of Oregon, a number of approaches were studied in the past year, including off-grid solar powered pumps, grid-tied community solar projects, and in-conduit canal hydropower systems. Ultimately three viable projects were identified:

1) North Unit Irrigation District/City of Redmond, Oregon Critical Facility Microgrid – offers combined in-conduit hydro and solar power generation.
2) Wallowa County/Joseph, Oregon Irrigation System Upgrades – centered on upgrades to a non-powered dam that will add a turbine as well as in-conduit power in canal feeders downstream.
3) Medford, Oregon Wastewater Treatment Plant Biogas Cogeneration System – centered on building out biogas storage and grid upgrades to power the plant, sell excess power, and provide emergency backup power (supplanting a diesel generator).

Each of these projects has characteristics that broaden the understanding of the value of microgrids employing renewable energy to achieve resiliency and net-zero carbon goals. The first two projects are centered on new hydropower within an irrigation system. The Medford project is only tangentially tied to an irrigation district. Despite this limitation, it was selected for study analysis as it was the only project mature enough (with sufficient data) to complete an analysis within this project year. Thus, we chose to move forward developing a case study, in concert with the Community Water-Power Resilience project, to demonstrate a method for evaluating such projects. Essentially, this case study serves as a template for studies to be carried out next year that more directly involve irrigation system hydropower.

Lastly, it is recognized that the locations and case studies in this report are all located in Oregon. We recognize this as a limitation. While the intent is not to ignore other states or regions, this result is driven by the fact that we have cultivated a collaboration with non-profit entities in Oregon that focus on these topics – Farmers Conservation Alliance and Energy Trust of Oregon. These partners were central to identifying projects that may be good fits for this program. A goal in the coming year is to establish collaboration with entities in other states/regions that, similarly, can connect us to potential projects in their geographic area.

The potential benefits from the WPTO's support for demonstration projects as energy solutions in irrigation districts include:

- Alternative power supplies for communities and farms using renewable, carbon-free energy resources.
- Cost savings for electricity for communities and farms.
- Resiliency of power supplies for critical loads when electricity from the grid is not available.
- Resiliency of power supplies for critical infrastructure in the event of catastrophic events.
- Demonstration of irrigation modernization projects that provide resilience and a reduced carbon footprint to irrigation districts and nearby communities. These deployments can serve as vanguards/archetypes spurring similar projects in other districts and states.

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ACRONYMS

AOP	Annual Operating Plan
CGT	Community-wide Green Tariff
COID	Central Oregon Irrigation District
CREP	Community Renewable Energy Program
DC	Direct current
DSM	Demand side management
FCA	Farmers Conservation Alliance
FID	Farmers Irrigation District (Oregon)
IM	Irrigation modernization
KDD	Klamath Drainage District (Oregon)
MID	Medford Irrigation District (Oregon)
NUID	North Unit Irrigation District (Oregon)
NWS	Non-wires solution
NZM	Net Zero Microgrid
OCPC	Oregon Clean Power Cooperative
ODOE	Oregon Department of Energy
OMD	Oregon Military Department
PGE	Portland General Electric
PPA	Power Purchase Agreements
PURPA	Public Utility Regulatory Policy Act
PV	Photovoltaic
TID	Tulelake Irrigation District (California)
TOU	Time of use
USFWS	United States Fish and Wildlife Service
WPTO	Department of Energy Water Power Technologies Office
WRRF	Water Resource Recovery Facility (i.e., wastewater treatment plant)

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PROJECT LEARNINGS

This report brings new understanding of energy solutions for irrigation modernization that extend from agricultural fields to irrigation districts which abut or encompass cities, towns, and counties where critical services reside. Those services require reliable, resilient power supplies. A significant conclusion of this report is that establishing microgrids with critical loads in critical locations within irrigation districts delivers both energy security and resilience to all stakeholders in the community.

The initial concept for the Energy Solutions project in FY22 was to explore opportunities in irrigation districts to offset on-farm pumping costs with grid-connected and/or off-grid solar panels. In April 2022 the study team was at the point to identify an irrigation site, where solar-plus-storage could be implemented for pumping and start collecting datasets to run a rudimentary model. Farmers Conservation Alliance (FCA) did not expect projects would have good economics in areas where the cost for power from the grid is extremely low (~$0.02/kW·h), even under favorable agricultural tariffs and with high TOU (time of use) prices quadrupling during peak demand. Nor was it expected that solar-plus-storage would be attractive as an investment. Solar-plus-storage may become attractive where the cost of power from the grid is high and peaks are high. DC solar to DC pumps might be an attractive option. Storage may be justified for resiliency. But when the sun is shining, solar will work; when it is not shining, it may be raining (thus, a limited need for irrigation).

The first places where information and data were sought were the Central Oregon Irrigation District (COID) and Farmers Irrigation District (FID) in Oregon. The results from a literature search and conversations with industry, vendors, and FCA on possibilities for solar-plus-storage for irrigation are discouraging. FCA has looked for opportunities for solar-plus-storage and in-conduit hydro to support irrigation pumps without promise, to wit:

- FID is a largely pressurized system There are very few, if any, on-farm pumps left. There are pumps that pressurize a portion of the piped delivery system, but this is an edge case in pumping, not a typical case. Given the widespread pressurization, FID cannot be considered a good case study.

- COID does not operate many, if any, pumps but their water users in open canal areas are pumping. There are significant expected energy savings as the district pipes and pressurizes its system. The district does not have energy use or load profile data for users. This data is a prerequisite for modeling and analysis.

- Farmers who currently flood irrigate, but plan to switch to sprinkler-based irrigation, may find power from an off-grid solar-plus-battery system viable due to the avoided capital cost of extending the grid to reach the new pump.

The report Off-Grid Solar Irrigation: Rural Farmer Implementation of Innovative Off-Grid Solar Irrigation Systems examines solar-plus-storage solutions for irrigation applications (power for pumps). The report is attached as Appendix C. The findings are not encouraging. Further inquiry on possibilities that may have become known since the report was published offered no further encouragement.[a]

Energy Trust of Oregon understands that a distinction must be drawn between in-conduit technology for energy efficiency and in-conduit power as an energy source (i.e., irrigation applications vs. power generation applications). Despite this shift in our perspective, a study focused on combining solar-plus-

[a] Conversation with Mason Terry, Director, Oregon Renewable Energy Center, author of the report for Energy Trust of Oregon.

storage with in-conduit power for pumps has not been successful due to the absence of irrigation load profiles and unavailability of data that is granular enough for modeling.

ENERGY COST REDUCTION IN IRRIGATION DISTRICTS

Energy Use in Pumps

Water pumping is a common energy use and a key expense for irrigation districts and irrigators across the western United States. Pumps are operated to move water during the irrigation season, approximately April through October, with some exceptions for drainage districts and other water right situations that can require pumping at other times of year. As droughts become increasingly common, impacting annual water reliability, irrigation pumping loads that were once consistent are becoming volatile due to lack of water availability. For example, in Oregon's Klamath Basin, drought severely restricted or excluded surface water from being used for agriculture in 2020 – 2022, dramatically reducing pumping loads from their historical averages. The reduction in pumping loads lessens the need for solar and storage, especially due to the increasingly intermittent nature of the loads themselves. There is no need for generation if there are no loads to serve.

Electric Utility Incentive Programs

NET METERING

Oregon's net metering statute requires all utilities, including investor-owned, public utility districts, municipalities, and cooperatives, to allow customers to install renewable generation facilities on their property to offset energy purchases. Irrigation districts with irrigation pumps with load profiles that are seasonal (and variable) are less able to make use of net-metering, compared to other utility customers that have more consistent loads.

DEMAND SIDE MANAGEMENT PROGRAMS

Electric utilities use demand side management (DSM) programs to incentivize customers to reduce electricity use during peak times. Pumping water for irrigation can represent a significant electrical demand, and utilities, including Oregon's Pacific Power, have DSM programs targeted at irrigation districts and irrigators.

The driving force behind a successful DSM program is customer response to a utility request for power reduction. Pacific Power's DSM program offers requests over three time periods: 1-day ahead, 4-hours ahead, and 1-hour ahead. Customers that reduce power during the requested period receive utility credits or cash incentives with a value that increases as the amount of advance notice decreases (e.g., 1-hour ahead is more valuable than 4-hours ahead).

However, there are obstacles to implementing successful irrigation DSM programs. DSM programs work well for groundwater pumping but cannot be used for most irrigation districts or irrigators operating pumps that move surface water. As groundwater is a relatively static resource, groundwater pumping can be shifted in time more easily. The same is not true for surface water.

For irrigation districts delivering surface water, turning off pumps during the irrigation season means that either water is not being delivered or, conversely, may mean that too much water accumulates where it is not wanted, causing flooding. Irrigators pumping surface water from canals also face a dilemma. For districts that operate "on rotation" – where only a portion of the district receives water every few days –

not taking water when it is available could mean the loss of a crop and the irrigator's livelihood. Irrigation districts and irrigators pumping surface water are unable to respond to DSM requests because of these operational limitations. Battery storage, charged by the grid or local solar would enable flexibility for demand response. FCA is looking at a cost comparison of the reduction of demand to the supply of electricity from solar-plus-storage at substations serving irrigation districts.

NON-WIRES SOLUTIONS WITH SOLAR AND STORAGE

Intelligently designed, integrated solar and storage systems could support both utility demand response goals and offset agricultural pumping costs. In Oregon, Pacific Power identified a circuit in the Klamath Falls area to evaluate potential "non-wires solutions" (NWS) to defer or avoid reconductoring a portion of the circuit that operates 16% beyond its load rating during summer afternoon demand peaks.

One or more solar and storage pilot projects sited in the appropriate area of the circuit could help the utility achieve its goals without reconductoring. Solar and battery storage could be co-located or could be sited individually. FCA is working with three irrigation districts near Klamath Falls (Klamath Irrigation District, Klamath Drainage District, and Tulelake Irrigation District) that operate large scale pumping plants in the area. These irrigation districts may be interested in making investments in solar and/or battery storage if the investment could help reduce district energy costs.

The structure for a pilot project has not yet been created. Once a structure and arrangements for a project are decided, a feasibility study, including system design, costs, and revenue streams can be undertaken. This would include the financial viability of the project for the irrigation district. In May 2022, FCA submitted the above concept in a proposal to Pacific Power for consideration as part of an NWS pilot project. FCA's proposal was selected for further review, and FCA and Pacific Power staff continue to discuss the concept.

INCREASED REVENUE THROUGH GREEN TARIFFS

Over the past year, FCA supported Central Oregon Irrigation District and Farmers Irrigation District in the creation of a green tariff program in their communities to enable the negotiation of new power purchase agreements at rates higher than available under the Public Utility Regulatory Policies Act (PURPA). Power regulatory and legal frameworks for power distribution are typically state specific. Nonetheless, the types of issues encountered working within or changing that framework are generally not unique, and therefore, experience in Oregon is generally illustrative of the issues that should be considered in other states.

Oregon's Community-wide Green Tariff (CGT), enacted by the 2021 legislature, is an investor-owned utility offering that allows communities to choose their own power supply. It empowers counties and municipalities to buy energy from locally sourced renewable energy projects. Historically, green tariffs were established by commercial and industrial customers wanting to meet self-imposed clean energy targets; however, local governments are now also looking to procure clean energy to meet their own sustainability and renewable energy targets.

Cities and counties are different from commercial and industrial clean energy buyers. Unlike corporate customers who may bring new demand for renewable energy, municipal customers are typically established, existing customers looking to shift their sources of electricity. Driven by public purposes, city and county governments often place strong emphasis on local benefits, which may manifest as a preference for nearby projects that can provide local environmental and economic value, while also improving grid resiliency. Sustainability and resiliency are key features in the motivations of many municipalities. CGT can provide a level of community-wide purchasing control not available through any other mechanism or program currently available to investor-owned utility customers.

At least six Oregon communities are actively engaged in exploring green tariff programs with either Pacific Power or Portland General Electric (PGE). The communities have widely varying goals and timelines for their work and are grouped below according to similarities:

> *City of Beaverton, City of Milwaukie*: These cities, served by Portland General Electric, were strong proponents of the utility-drafted state legislation that enabled green tariff programs in 2021. Both communities have remained interested in pursuing the fastest and least-cost method of increasing the amount of renewable energy supplied to their communities, perhaps by purchasing large amounts of renewable energy certificates. Neither community has been interested in engaging in discussions around the role that irrigation district-owned energy facilities could play in supporting their communities' energy goals.

> *City of Bend, City of Hood River, and Hood River County*: These communities, served by Pacific Power, are strongly connected to agriculture and closely co-located with existing and potential irrigation conduit hydropower projects. Each community has worked with the utility to understand the steps required to move through the development of a green tariff. As those steps have become clearer, there is an increasing recognition from the communities that creating a green tariff program will be a significant undertaking that requires time and consideration due its long-term nature. In addition, Oregon's adoption of a 100% clean energy standard by 2040 is causing each community to review its previously approved climate and energy goals. FCA's efforts have focused on ensuring that local irrigation district staff are connected to decision makers in the community exploring green tariff options so that they can share the potential benefits of including local projects within the program.

> *City of Portland, Multnomah County*: Served by PGE, the state's largest communities are also interested in the potential for a green tariff program to support their climate and energy goals. As with the Bend and Hood River communities, there is increasing recognition that adopting a green tariff will require significant work and may entail revisiting previously approved goals. Compared to the Bend and Hood River communities, these entities note strong concerns that any green tariff option does not create an additional economic burden on low-income ratepayers and are looking for community voices to lead in the thinking and creation of tariff options.

The FCA will continue to support and analyze this concept, but it will likely be some time before an exemplar green tariff program is implemented.

IRRIGATION MODERNIZATION AND ENERGY GENERATION IN IRRIGATION DISTRICTS

Irrigation modernization commonly refers to replacing open irrigation canals with subsurface pipes. The water is pressurized and managed for more efficient irrigation. In-conduit power commonly refers to using pressurized water in conduits (i.e., pipes) as an energy source for hydroelectric generation.

The Energy Solutions project aims to apply the efficiencies of in-conduit power to applications in irrigation districts to serve local customers with carbon-free electricity in resilient microgrids. Once in-conduit irrigation technology is installed and energy efficiency measures are implemented as part of irrigation modernization, there are few opportunities for cost reduction in pumping. However, opportunities exist for distributed energy resources to be utilized in irrigation districts for resiliency in the communities within or adjacent to the district and in the grid that supplies electricity to the district. FCA and INL are working to identify energy solutions to reduce energy costs while supporting electricity grid needs. Solar and energy storage in microgrid configurations with in-conduit hydroelectric generation is a solution that stands out and is a candidate for a pilot project to demonstrate its technical and economic viability.

Off-grid Solar and Storage

Research over the past few months has shown that power for irrigation pumps in the field from in-conduit power is not economically attractive, given the low electricity tariffs in Oregon. Further, distributed generation powered from in-conduit hydropower would not be competitive and could only be justified for resiliency. Its feasibility would depend on the diversion of water supplies through canals, pipelines, aqueducts, and other man-made structures that are fitted with electric generating equipment. Available land and access to loads – such as large pumps that service a community, rather than an in-the-field pump – are also required. Such a favorable situation has not come to our attention over the course of our inquiries.

Solar powered pumps are the best fit. Very good equipment is available on the market for this purpose, mostly marketed in California where high electric rates justify the cost.

Modeling of off-grid solar-plus-storage in microgrids, even for a hypothetical use case would be speculative due to the lack of data. Data on loads is generally only available on a seasonal basis and not granular enough for modeling power requirements. The business case does not justify such a model on a speculative basis. Based on outreach performed by FCA, customers are interested in resilience but are not clamoring for projects that deliver it. The most notable example of an expressed need for resiliency is the impact of a Cascadia earthquake on energy and electricity supply in Oregon.

Grid-tied Community Solar Projects

MEDFORD IRRIGATION DISTRICT FLOATING SOLAR ARRAY

In the spring of 2020, the Oregon Clean Power Cooperative (OCPC) contacted FCA to discuss opportunities and considerations for installing a floating community solar project on the surface of a district retention pond. Medford Irrigation District (MID) was identified as a potential location because the district is located within Pacific Power territory and close to interconnection access.

Depending on the location and climate conditions, floating solar projects are estimated to reduce reservoir evaporation rates by 10%. Floating solar may also inhibit the growth of algae and other aquatic plants below the panels. Further, as an Oregon Community Solar Program project, the energy generated by the system could benefit both the district and other water users. Under the program's rules, 40% of the energy generated from the community solar project would be made available to MID, 50% would be made available to offset the residential use of individual district irrigators, and 10% would be reserved for low-income rate payers.

As proposed, the system would be an 867 kW photovoltaic array occupying approximately two acres of the reservoir. The system would be expected to produce up to 1,370,000 kWh per year, with energy generated by the array appearing as a credit on subscribers' electricity bills, lowering the costs paid to the utility for energy.

An interconnection study indicated a project would be technically feasible, but subsequent financial analysis showed that the project had costs that were not easily offset by available grants. In March 2022 grant funding opportunities expanded. FCA and OCPC developed an application for a Congressionally Directed Spending request in support of the project and subsequently submitted a grant application to the new Oregon Department of Energy Community Renewable Energy Program (CREP). Pending the outcome of the grant applications, more detailed analysis may be warranted to support development of the project.

LAKE MILLER SOLAR PROJECT

Klamath Drainage District (KDD) in Oregon is interested in developing a utility-scale solar installation to offset the energy costs associated with pumping irrigation water. The district owns approximately 1,000 acres of land within Lake Miller that could potentially be used, either directly or indirectly, for a utility-scale solar installation to generate revenues that would offset electricity purchases. Lake Miller is an ephemeral wetland located south of Klamath Falls and adjacent to the California border. The lake is categorized as a wetland and is zoned for exclusive farm use. However, it has poor soils that make it unsuitable for most agricultural uses. In the past, during wet years, the district has leased the land for grazing.

Lake Miller being a protected wetland complicates the permitting process for a solar project. Research on property ownership in the area found that bordering parcels are owned by US Fish and Wildlife Service (USFWS). A land exchange could give USFWS ownership of most or all of Lake Miller, uniting Lake Miller under single ownership. In addition, KDD is willing to consider water deliveries to Lake Miller to reinvigorate the land's wetland functions.

It is also important to note that Pacific Power will be removing several dams that produce hydropower on the Klamath River beginning around 2024. As these hydropower units go offline, the existing transmission system in the area may have unused capacity. This capacity could make siting a utility scale solar project in the area more feasible if solar-ready land were identified along or near the utility's transmission pathway.

KDD and FCA will investigate the potential for a land exchange with USFWS or the Bureau of Land Management. Should a viable parcel be identified, further technical and economic analysis can be carried out.

Microgrid Projects in Irrigation Districts

Projects to develop microgrids in irrigation districts for non-agricultural applications (e.g., food processing, community resilience) are viable. Benefits and services from these microgrids are shown in the tables below.

Benefits of In-Conduit Power in Microgrids with Solar and Storage

• Resiliency – energy for critical services
• Revenue (from grid services)
• Savings from net-metering
• Carbon reduction

Critical Services Supported by Microgrids in Irrigation Districts

• Airport

• Fuel pumping
• Agricultural water pumps
• Emergency shelters
• Schools & community centers
• Fire & police stations
• EV charging stations
• Cell phone/communications towers
• Food processing facilities
• Grocery stores
• Drinking water treatment and distribution facilities
• Wastewater treatment facilities
• Fairgrounds - functioning as emergency/fire camp/staging operations, community centers, livestock housing, evacuation centers

CASE STUDIES IDENTIFIED

With the goal to demonstrate viable energy solutions tailored to individual communities, three potential case studies have been identified. Two of these, along with the two community solar projects described above, need more time to mature to the point that detailed analysis can be undertaken Each of these projects are good candidates for further development in FY23. The third case study is more refined, and as such, was amenable to a techno-economic analysis.

Redmond Airport/North Unit Irrigation District Microgrid

With grant funding from Energy Trust of Oregon, Farmers Conservation Alliance and OS Engineering are conducting a study examining the potential to provide backup power using renewable energy to several critical facilities in the Redmond, Oregon, area: municipal drinking water wells owned by the City of Redmond, the Redmond Airport, the Oregon Military Department's (OMD) Biak Training Center and an additional planned OMD Readiness Center.

North Unit Irrigation District's (NUID) irrigation canal is adjacent to the Redmond Airport. In-conduit hydropower is an alternative to diesel generators for backup electricity for an extended period in the event of a large-scale power disruption. Notably, this location hosts a disaster response and coordination center that is planned as the command and control hub for the State of Oregon in the event of a large scale Cascadia fault earthquake. While NUID's canal typically only operates during the irrigation season, in an emergency, water could be supplied to generate power at any time of year. The pipeline associated with the in-conduit hydropower facility would also support the district's larger irrigation modernization efforts by conserving water and improving water supplies for local farmers. In addition, there are established solar and in-conduit hydropower installations within a few miles of the airport that can be included in the electrical boundaries of a microgrid. See Appendix A for more details.

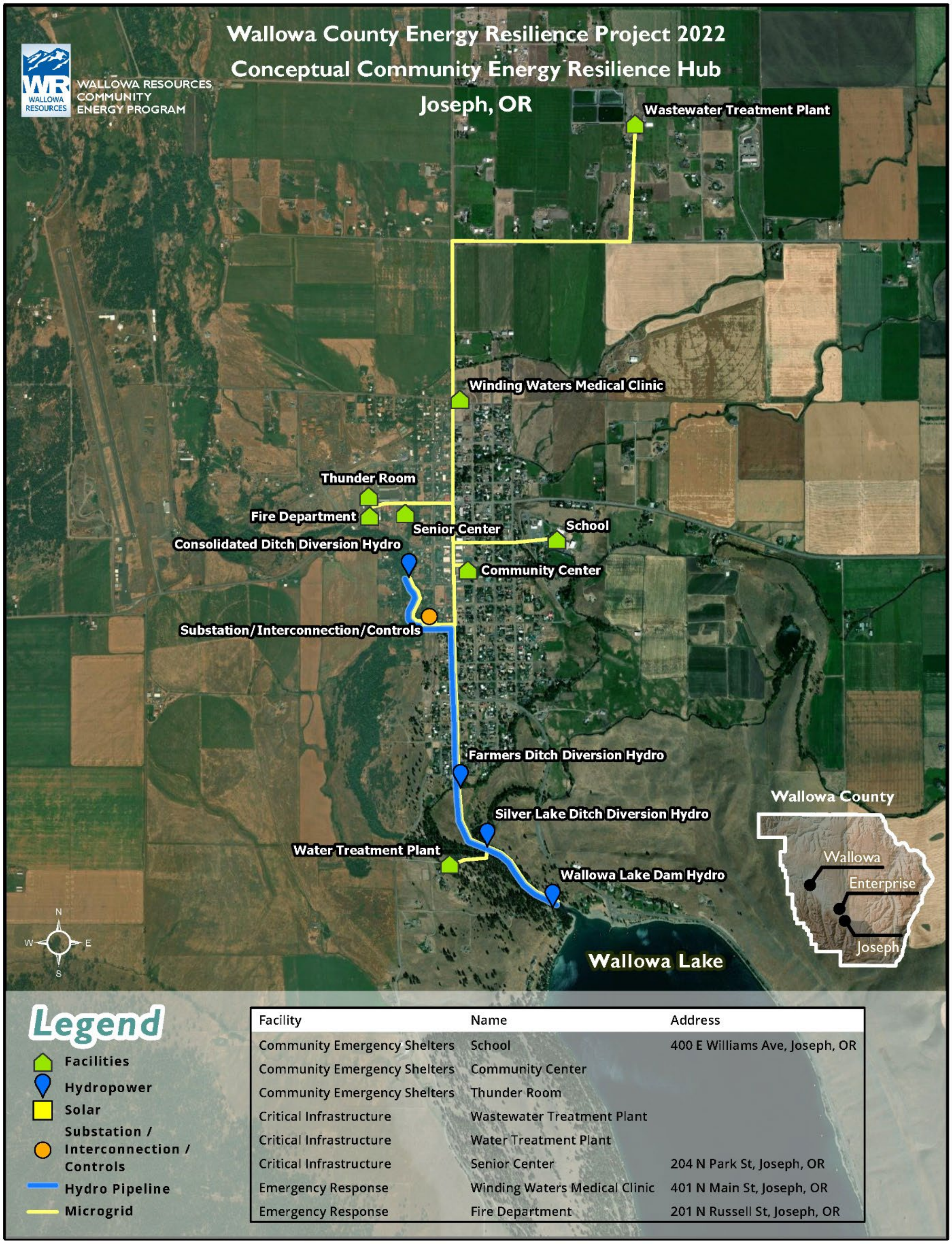
Early on, this project looked like the most promising for detailed analysis this year. However, impediments to getting data on airport vendor power demands have significantly delayed this project. The hope is that the required data will be available in FY23.

Wallowa County Community Energy Resilience Hub (Joseph, Oregon)

Energy Trust of Oregon brought two projects to INL's attention. The first one is centered on refurbishment of a non-powered dam in Wallowa County, Oregon. The state has already funded refurbishing the dam, including adding fish passage. As part of the refurbishment, the local community, Joseph, Oregon, wishes to add power generation to the dam, as well as in-conduit hydro to several feeder canals that initiate downstream of the dam.

Joseph is a small community located at the end of a power distribution line. If that line were compromised, the community and surrounding irrigation district may face an extended power outage. The proposed integrated system would provide a resilient, zero-carbon microgrid that would serve several critical community functions – a medical clinic, fire department, emergency shelters, schools, a senior center, and water and wastewater treatment facilities. See Figure 1 for the layout of the proposed resilience hub.

While this project is conceptually sound, it is not yet ready for more detailed analysis. Once the project matures, INL can perform analytical and feasibility studies with the IrrigationViz and Net Zero Microgrid (NZM) modeling tools.



Facility	Name	Address
Community Emergency Shelters	School	400 E Williams Ave, Joseph, OR
Community Emergency Shelters	Community Center	
Community Emergency Shelters	Thunder Room	
Critical Infrastructure	Wastewater Treatment Plant	
Critical Infrastructure	Water Treatment Plant	
Critical Infrastructure	Senior Center	204 N Park St, Joseph, OR
Emergency Response	Winding Waters Medical Clinic	401 N Main St, Joseph, OR
Emergency Response	Fire Department	201 N Russell St, Joseph, OR

Figure 1. Wallowa County, Oregon, Energy Resilience Project diagram, July 2022. The project is anchored by the addition of hydropower generation to the Wallowa Lake Dam (located at the bottom of the image) and the canals it feeds.

Medford Regional Water Reclamation Plant Microgrid

The second project presented by Energy Trust of Oregon combines a biogas co-generation unit with the potential for community solar and storage in a microgrid configuration in Medford, Oregon. Presently, the water resource recovery facility (WRRF, aka wastewater treatment plant) in Medford has a 750 kW cogeneration system installed that is fired by biogas produced by the treatment process. The cogeneration unit's output is curtailed to no more than 425 kW because the system does not have a utility-required relay installed that would enable power export (i.e., net metering). The emergency backup power source is a diesel generator.

The goal of the upgrade project is to create a net-zero microgrid that is able to operate in an islanded mode for an extended period during a grid outage. The facility discharges to the Rogue River which is the drinking water supply of downstream communities. In the event of an extended power outage, the facility would be forced to discharge untreated sewage to the river.

The facility has a number of options to weigh for the design of the project.

- Installing the required relay to enable running the cogeneration unit up to its 750 kW rated capacity and selling excess power back to the utility.
- Integrating solar PV arrays sited on unused land within the treatment plant boundaries
- Integrating a potential community solar PV array located nearby
- Installing storage capacity for biogas to replace the diesel storage tank and generator – using the cogeneration unit in islanded mode as the emergency backup power supply
- Integrating battery storage
- Accepting waste from a nearby food processing facility to increase the output of the cogeneration unit

Of interest to the Medford WRRF was an analysis of configuration options for the system. Of all of the projects considered for a case study, this one offered the best combination of maturity of the concept, readily available data on loads and demand patterns, and green energy deployment. Conversely, the project is only tangentially related to an irrigation district and irrigation modernization. In this case, the substation serving the WRRF also serves the nearby Medford Irrigation District. Development of a green microgrid anchored by the power generation potential of the WRRF serves to improve the resilience of both the community and the irrigation district. Further, by doing the analysis on the Medford WRRF microgrid, we have established a process and template for similar analyses of projects that more directly integrate irrigation district assets.

A detailed study for this microgrid was conducted by ProtoGen under the Community Water-Power Resilience project funded by WPTO. The complete report documenting ProtoGen's analysis is available through the Community Water-Power Resilience project. A summary of the modeling and analysis can be found in Appendix B of this report.

CONCLUSIONS AND RECOMMENDATIONS

The Energy Solutions project is designed to characterize differences in irrigation modernization pathways, designs, the role of hydropower, and outcomes based on the heterogeneous physical and jurisdictional conditions that exist across the western U.S. The focus of the project has shifted from analysis and tool development to identifying opportunities for actual deployment of modernization projects. The learnings of the project confirm that this shift in focus is the way to achieve the goals of the AOP.

The project views irrigation districts as integrated water and power systems. The project team identified opportunities for the deployment of modernization projects in irrigation districts that include in-conduit hydro, solar, and storage. Those opportunities substantiate that irrigation district-based hydropower is a valuable source of energy – along with solar, storage, and controllable loads – in microgrids that serve rural communities. Further, microgrids configured in this manner are an important asset for serving critical loads when there are extended outages in distribution and transmission systems.

FCA extensively researched ways to overcome barriers to energy solutions in the context of irrigation modernization. This was done in coordination with external stakeholders and irrigation practitioners. Among the topics considered were reducing interconnection costs; aggregating hydropower, solar, and batteries in microgrids; net metering; and green tariffs. Several of the opportunities identified by FCA will require more time to fully evolve. This report captures the distinctive parameters of each, notes the barriers to their realization, and tries to show how they can correlate to future projects.

The project team identified three prospective projects on which to focus. Development and analysis of the Redmond/NUID microgrid concept and the Wallowa County resilience hub project will continue into next year. The most mature of them, the Medford biogas cogeneration system, was analyzed using XENDEE design and planning tools. The analysis was carried out under the Community Water-Power Resilience project, as the proposed concept fit best within that project.

The results of this analysis are persuasive that preparing feasibility studies is an effective way to demonstrate the benefits of microgrid concepts for irrigation districts and rural communities. We recommend funding additional feasibility studies in FY23 that look at projects focused on varied approaches to achieving more resilient irrigation district and rural community water and power systems. In parallel, we will work to develop partnerships in other states that will lead us to promising, more geographically diverse modernization projects.

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San Gabriel Valley Water Company "Plug-and-Play" In-Conduit Hydropower Development Project, CEC-500-2021-032, May 2021.

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APPENDIX A – REDMOND AIRPORT AREA CRITICAL FACILITY ENERGY RESILIENCE STUDY SUMMARY, APRIL 2022

Redmond Airport Area Critical Facility Energy Resilience Study

Background and Purpose

With grant funding from Energy Trust of Oregon, Farmers Conservation Alliance (FCA) and OS Engineering are conducting a study examining the potential to provide backup power using renewable energy to several critical facilities in the Redmond area: municipal drinking water wells owned by the City of Redmond, the Redmond Airport, the Oregon Military Department's (OMD) Biak Training Center and an additional planned OMD Readiness Center.

In the event of a major Cascadia Subduction Zone Earthquake, Redmond's Municipal Airport is planned to be an emergency operations center for the State of Oregon. The new Oregon National Guard Readiness Center adjacent to the airport may also play a role as a command post for state government and federal emergency response. A major earthquake is expected to impact the regional electrical grid, meaning many critical facilities may require long-term, reliable backup power. Although diesel generators often supply backup power in emergencies, in the aftermath of a major earthquake liquid fuels for generating electricity may only last several days to a week and supply lines for liquid fuels are expected to be disrupted for a significant amount of time. There will also be a need for reliable electricity maintain local critical services during such an emergency.

North Unit Irrigation District's (NUID) irrigation canal adjacent to the Redmond Airport may offer an alternative to diesel generators: in-conduit hydropower that can produce backup electricity for an extended period in the case of a large-scale power disruption. In-conduit hydropower is a reliable technology that can operate 24 hours a day, seven days a week. While NUID's canal typically only operates during the irrigation season, in an emergency water could be supplied to generate power regardless of the time of year. The pipeline associated with the in-conduit hydropower facility would also support the District's larger irrigation modernization efforts by conserving water and improving water supplies for local farmers. In addition, there are several other existing solar and hydropower installations within a few miles of the airport.

The purpose of this study is to:

- Identify and characterize the energy requirements of the critical facilities near to the potential North Unit Irrigation District (NUID) hydropower facility,
- Explore at a high-level, in coordination with Pacific Power, the capacity of the nearby distribution system to accept renewable generation from the potential hydropower unit or to route power from other existing generation sources, and the kinds of upgrades that could be required to use a portion of the distribution system as a micro/mini-grid to deliver power to the critical facilities during grid outages,
- Determine if the hydropower capacity and generation available in the NUID canal system under different water availability scenarios could meet the energy requirements of the critical facilities,
- Determine the potential additional energy requirements necessary to support the critical facilities, such as could be provided with solar and/or battery storage,
- Determine next steps for project feasibility and development. Pending the outcome of these activities, the critical facilities and NUID could choose to move forward with appropriate next steps in project study and development.

Study Activities

FCA and OS Engineering are focusing their efforts across three main activity areas:

- Activity 1: Data procurement and analysis
- Activity 2: Utility coordination and grid upgrades assessment
- Activity 3: Reporting and identification of appropriate next steps

Activity 1: Data procurement and analysis

Working with the critical facility owners, FCA and OS Engineering will:

(i) Identify the grid interconnection points of the critical facilities,
(ii) Assess the scope and duration of electrical needs at each critical facility during a grid outage,
(iii) Gather and analyze interval energy use data for each critical facility,
(iv) Estimate the hydropower generation and capacity potential available, and
(v) Compare the analyzed facility energy requirements to the estimates of hydropower generation and capacity potential, noting gaps in energy or capacity.

For the critical facilities, the energy analysis will assume the need to cover 100% of typical electrical loads for a two-week outage with a 50% confidence interval for each hour during the irrigation season.

The hydropower capacity and generation analysis will use flow records from the US Bureau of Reclamation's Hydromet Gauge near the North Unit Main Canal diversion (NMCO), adjusted for estimated water losses of approximately 28 cfs between the diversion and the potential hydropower site, to create a set of three flow scenarios:

- Historical average daily flows over the last 10 years.
- A low-water year scenario, based on discounting flows from the last two-to-three years by a factor to be determined with assistance from NUID staff.
- A future-reduced-diversion scenario, created with assistance from NUID staff.

The project team will create hourly generation profiles for the potential hydropower facility based on the flow scenarios and modelled head available under the differing flows, using a set of standardized piping assumptions.

Activity 1 Deliverables:

- A list of the critical facilities and their interconnection points on the local distribution circuit
- Spreadsheet(s) with at least one year, and preferably 3-5 years, of 15-minute or hourly interval energy usage data for each critical facility and a summary of the analyzed interval energy use data, include average and peak capacity (kW) and average annual use (kWh)
- Spreadsheet of estimated hourly generation for the proposed hydropower facility over three flow three scenarios; including estimates for planned or unplanned outages, average and peak capacity (kW) as well as average annual and monthly generation for each scenario:

Activity 2: Utility coordination and grid upgrades assessment

FCA and OS Engineering will coordinate with Pacific Power to determine the conditions and potential upgrades necessary on the local grid to enable the creation of a micro/mini-grid to power the critical facilities and to interconnect the potential hydropower facility. If required, FCA will request a pre-application report for an identified interconnection point.

Activity 2 Deliverables:

- Summary notes from utility coordination meetings and any data provided by the utility
- Interconnection pre-application report, if requested

Activity 3: Reporting and identification of appropriate next steps

FCA and OS Engineering will write a report summarizing the findings, implications, and considerations of Activities 1 and 2 and include next steps for the critical facilities and NUID to consider if they desire to further study the project. The report will also document the names, titles, and contact information of engaged stakeholders.

Activity 3 Deliverables:

- A concise written report summarizing (i) the energy requirements of the critical facilities, (ii) the comparative capacity and generation of the potential hydropower project in relation to the critical facilities, (iii) the remaining energy and capacity that may be required to fully meet the energy requirements of the critical facilities, (iv) the findings of the interconnection pre-application report, (v) the potential utility grid upgrades to serve energy to the critical facilities in the case of an outage, and (vi) identified next steps, included suggested timing, for the critical facilities and NUID to consider if they choose to move forward with further study.

Estimated project timeline

- Activity 1 - Facility data procurement and analysis – ~May through June 2022
- Activity 2 - Utility coordination, interconnection pre-application report, and grid upgrades assessment – ~May through mid-August 2022
- Activity 3 - Reporting and identification of appropriate next steps – ~August through September 2022

APPENDIX B – MICROGRID STUDY SUMMARY, REGIONAL WATER RECLAMATION FACILITY, CITY OF MEDFORD, SEPTEMBER 2022

REGIONAL WATER RECLAMATION FACILITY, CITY OF MEDFORD, OREGON

MICROGRID STUDY

BACKGROUND

The June 2022 Interim Report made clear that renewable energy and energy storage-based microgrids represented the most helpful energy solution for irrigation modernization within the Oregon's irrigation districts. Further, it was evident that those microgrids could be most advantageously sited within small cities, primarily due to their large controllable loads such as wastewater treatment facilities.

Idaho National Laboratory agreed to provide a no-cost study evaluating alternatives for a microgrid anchored by the Medford water resource recovery facility. The study was conducted by ProtoGen, Inc., a partner in the INL Net-Zero Microgrid (NZM) Program. The NZM program has an objective of increasing awareness of strategies for improving critical facility resilience, sustainability, and economic conditions. The Energy Trust of Oregon was also a valued partner, offering helpful guidance and advice throughout the study activities.

Task Limits in Study

The tasks included in the scope of work for the study were constrained by available time and funding. The scope of the study was limited to preliminary modeling and analysis. The study commenced on July 15, 2022, with completion required by the end of September. A comprehensive feasibility study would have taken an additional month.

The delivery of this study within the limited time period demonstrates that the microgrid design and planning tools and methodology used by the contractor – site survey, 3D modeling, and techno-economic modeling using the XENDEE/INL NZM platform – is both efficient and cost effective. This approach can be used to expedite feasibility studies for distributed energy resources and microgrids in rural communities and to screen proposals for government-funded grants.

ProtoGen Selection as Contractor for Study

Through the Community Water-Power Resilience project, INL contracted ProtoGen, Inc. to conduct the study and to prepare a report communicating the results. ProtoGen was selected because of its technical expertise and its demonstrated experience using the XENDEE microgrid design and planning platform – the primary tool used for INL's Net Zero Microgrid Program.

Medford Regional Water Reclamation Plant

The Regional Water Reclamation Plant in the city of Medford treats wastewater prior to discharge to the Rogue River. It processes an average of 15.6 million gallons per day (MGD) of influent flow. The treatment facility has undergone several upgrades and expansions, keeping pace with advancing technologies, regulatory requirements, and the changing needs of the community. The facility is an attractive candidate for a microgrid because significant capital expenditures have been made on technology improvements in recent years, including 1 MW of diesel standby generation and a 775 kW Combined Heat and Power (CHP) plant fueled by an onsite anerobic biodigester. Facility bio digestion capacity has been increased as of 2022, with plans to further enhance capacity by accepting locally sourced food and animal waste for a tipping fee (i.e., a waste disposal fee).

The city of Medford and the water reclamation division are committed to increasing system resilience and protecting both the environment and the economic well-being of the residents and businesses in the community. This commitment guides the modeling and analysis in this study.

APPROACH TO THE STUDY

Medford fully engaged with ProtoGen during this study, with active support from the Energy Trust of Oregon and Idaho National Laboratory. During the initial meeting, views were expressed on facility resilience, sustainability, and economic goals and objectives. A team of technical experts from ProtoGen reviewed the type and quantity of site-specific data that would need to be collected. A consensus emerged from the discussion on the desire to identify and evaluate potential energy resilience configurations that could leverage the existing facility resources and move them toward a net-zero microgrid system.

The study began by collecting all relevant location-specific data from Medford, including Pacific Power electric and Arista natural gas utility billing, plant flow, equipment and maintenance costs, among other required modeling inputs. ProtoGen conducted a virtual site visit using Google Earth to verify significant site assets and boundaries, followed by a physical site visit. The two-day visit was highly productive: one hundred and forty equipment-specific images were collected, the team took a site tour to verify that existing equipment matched documentation, and a review of site operations led to invaluable insights. A drone was used to capture more than 2000 images. Photogrammetric techniques were used to create a high-resolution 3D point cloud and digital terrain models from the drone images. The digital results were imported into Sketch-Up to further develop 3D modeling of potential system layouts. This method assures decision makers that the proposed future assets would physically fit within the site and can show the potential for shading from adjacent objects, which can significantly impact solar photovoltaic (PV) production and energy yield.

Baseline facility energy usage is a key input to the modeling software. Monthly data was provided and interpolated to create the load profile shown in Figure 1. While hourly or 15-minute interval level data is optimal, it could not be gathered in time for the study. The facility’s electric utility, Pacific Power, was contacted and confirmed that it does not have metering in place capable of recording high-resolution data. Additionally, during the site visit a facility-owned data historian server was identified as having likely collected the level of data required. After significant effort through meetings, calls, and emails, the City of Medford’s IT vendor, Portland Engineering, did not deliver the requested data. The report strongly recommends that the City of Medford actively pursue its vendors to obtain the facility data.

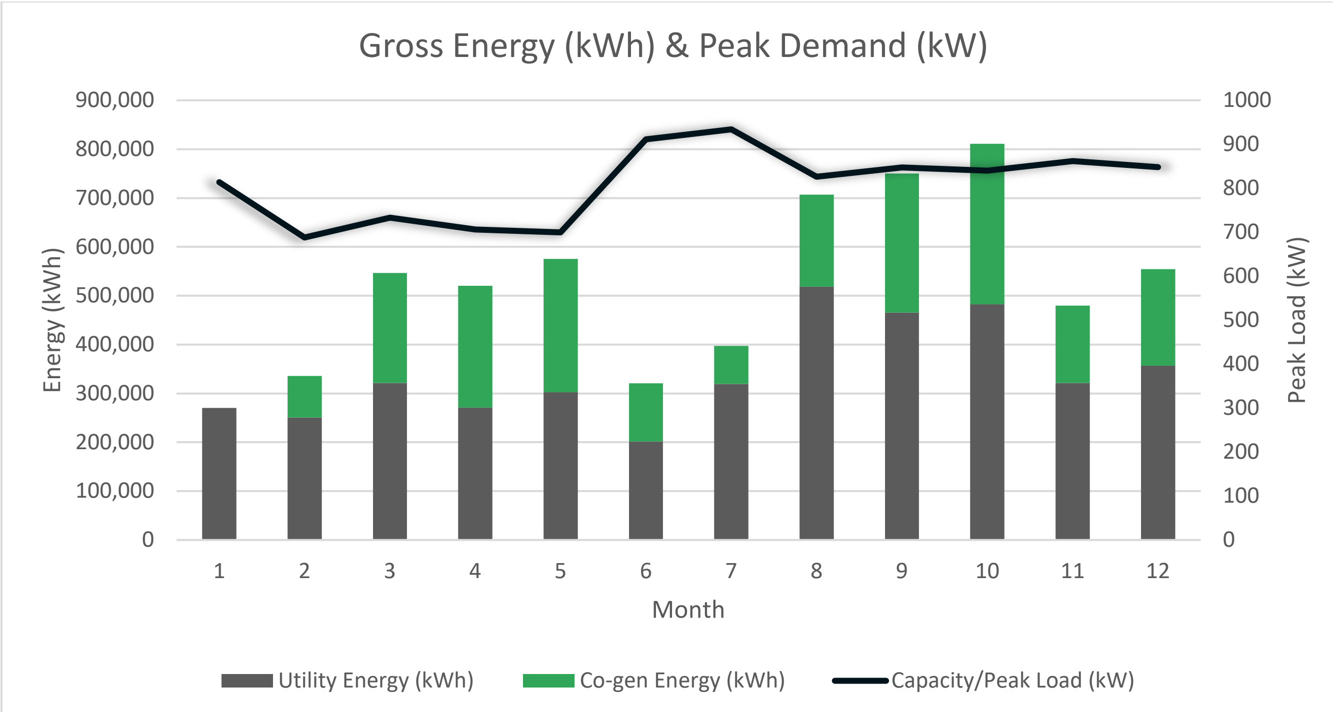

Figure 1. Annual energy usage in kW (Medford Study, ProtoGen)

Data collection – especially gaining access from utilities and vendors – is a difficult and time-consuming process. This data is essential for accurate modeling and analysis, especially for feasibility studies. The limited access to data is a major barrier to deploying distributed generation and storage and establishing microgrids in irrigation districts and communities.

TECHNICAL DATA AND ASSUMPTIONS

Technical considerations, data inputs, and assumptions used for the modeling are described below. The analysis of these inputs and assumptions produced technical findings for the design and planning of the microgrid. See Key Technical Findings.

Electricity

Load data was created from monthly billing data and correlated against monthly co-gen production data. This data was scaled against that from a comparable facility to create an hourly load profile.

Natural Gas Thermal

The facility consumes natural gas to fuel boilers for heat. The current assumption is that natural gas service will be available during a grid outage.

Solar PV Sites

Three potential solar PV sites were investigated to determine maximum hosting capacity. The sites were recommended by facility leadership based on future expansion plans.

No studies were performed for environmental considerations such as flood zones, wetlands, or wildlife habitats. These would be mandatory for a future feasibility study.

Co-generation Fuel

The annual fuel available to the co-gen plant was capped for all model simulations at the approximate annual burn volume in the data. It was assumed that fuel generated by the digester was burned to generate energy in the co-gen engine. However, it was noted during the site visit that the facility does flare gas when it is not capable of exceeding co-gen output limits agreed to with the electric utility. The exact quantities of biogas from digestion would require further engineering for a detailed analysis.

MODELING AND SCENARIOS

The technical data and assumptions in the above section, as well as the Pacific Power utility tariff, existing site conditions, and 3D modeled solar PV, were input into XENDEE, a microgrid modeling tool that performs multivariable analysis. A long duration (two week) resilience event was used as the basis for all scenarios. Working iteratively, the modeling and other tools were used to develop 15 scenarios that together form the contours of potential solution sets. Of those, six were selected for further consideration against the stated objectives of resilience, sustainability, and economic operation.

OPTIMIZATIONS OF SCENARIOS FOR A MICROGRID

The six scenarios selected for optimization for a microgrid are described individually in the ProtoGen report. The six scenarios are as follows:

1. Optimization #9: Baseline Reference – No Co-gen
2. Optimization #10: Cost reduction
3. Optimization #11: 450kW Limit on Co-gen with CO_2 reduction premium at 1.5
4. Optimization #13: No limit on 775 kW co-gen, CO_2 premium factor of 1.25
5. Optimization #14: Economic run without existing CAT and no limit on co-gen
6. Optimization #15: Economic run without existing CAT and 450kW limit on co-gen

The scenarios are visualized in charts over a 24-hour period. The charts display the load to be served and how the load in each hour is met according to resource type. While the software looks at every hour of every day, the example day shown is an average day during a grid-down emergency. The scenario for "Optimization #14: Economic run without existing CAT and no limit on co-gen" is described below.

Optimization #14 is predicated on an economic solution during both emergency and non-emergency conditions based on the elimination of the CAT diesel standby generator but with full co-gen capacity. The modeling results in the addition of 1,017 kW of PV with 1.6 MWh of battery energy storage system (BESS). This scenario differs from #13 in that it does not value CO_2 emission reductions achieved by replacing diesel with biogas.

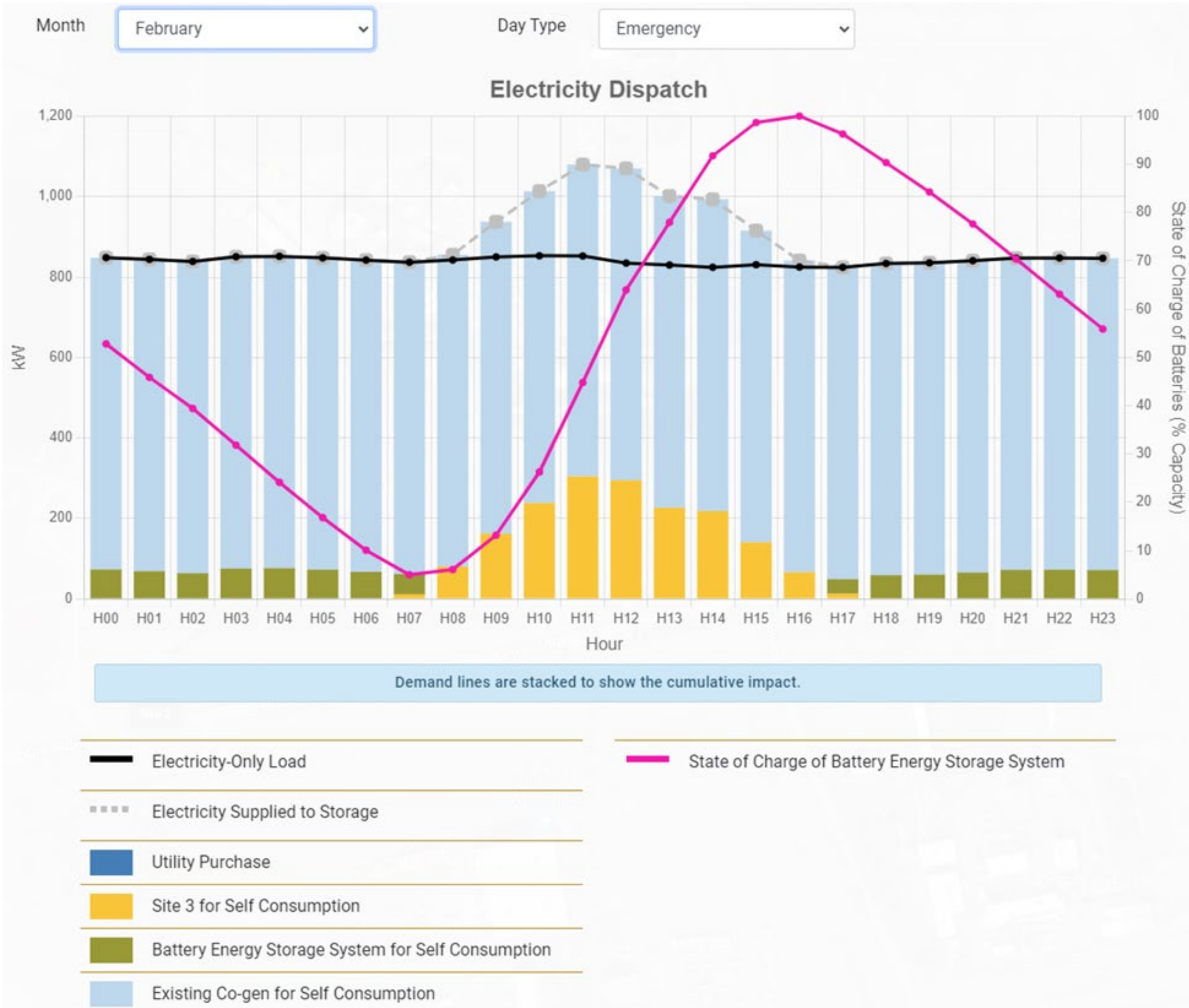

Figure 2. Optimization #14 emergency dispatch curve (Medford Study, ProtoGen)

Careful visual analysis of the charts and the variations between are intended to inform decision points for Medford to consider before moving forward with a final design concept.

COST CONSIDERATIONS

The City of Medford must duly consider their organizational mandates and public opinion when balancing resilience and sustainability goals, economic outcomes, and capital costs. Ultimately, whatever the optimal solution for a particular community, achieving CO_2 reductions while maintaining resilience capabilities has cost implications. Doing anything costs more than maintaining the status quo. In the example of Medford, significant investments would have to be made in their facilities. This investment in sustainability and resilience brings with it the benefits of carbon reduction.

Estimated capital expenditures (CapEx) for each of the six optimized scenarios for Medford are shown in Table 1 below. The values for the configurations of each modeled systems and corresponding CapEx budgets are indicative only. Note that the costs for reconfiguring the electrical service, utility interconnection fees, and biogas production and storage systems are not included, as they were outside the limited scope of this study. These would be included in a comprehensive feasibility study.

Table 1. CapEx by Optimization Scenario (Medford Study, ProtoGen)

	OPT#9	OPT#11	OPT#12	OPT#13	OPT#14	OPT#15
SOLAR PV (KWDC)	n/a	3,683	2,410	2,365	698	4,321
ESS ENERGY (KWH)	n/a	6,384	2,568	3,689	1,103	6,436
ESS POWER (KW)	n/a	1,915	770	1,107	331	1,931
CAPEX	$0	$9,611,329	$6,685,246	$6,993,191	$1,952,401	$12,913,899

KEY TECHNICAL FINDINGS

The modeling and analysis in the Medford study demonstrates multiple pathways to move forward with the development of solar PV, BESS, and biogas CHP. In general, the best overall outcome from the study was found to be one that maximizes biogas production with or without gas storage. The gap between generation and peak load was reasonably serviced with solar PV and BESS.

To achieve an optimal configuration Medford would have to do several things. Among them are:

1. Gain access to the onsite historian or otherwise develop high resolution facility energy data; preferably a year's worth of hourly or sub-hourly data.
2. Develop a detailed feasibility study and schematic design sufficient to engage the electric utility and issue a bid document to gather firm pricing.
3. Plan to produce and/or store enough biogas to sustain the engine during a 2-week outage.
4. Complete a new interconnection study with Pacific Power.
5. Potentially invest in substation upgrades.
6. Reconfigure facility electrical distribution to allow for the CHP to operate in support of the emergency loads and interconnect the new PV and BESS.
7. Commit an amount of currently open space to solar PV and BESS.

Future modeling and engineering should provide storage requirements for bio-digester output and sizing of the digester. This will result in increased self-sufficiency and resilience. Additional engineering will be required to determine the feasibility of satisfying all heat/thermal demands with co-generation.

There are opportunities for revenue from the microgrid. For example, as currently configured, the CHP is not allowed to export energy to the grid and is curtailed to 450 kW. The export of power would require investing an additional $250-$500k to upgrade a Pacific Power substation according to existing studies (note that new substation work adjacent to the facility was recorded during the site visit). The benefit that can accrue from the export of power is dependent on the regulatory environment and the cooperation of the electric distribution utility for interconnections, substation upgrades, and two-way power flows.

The findings of this collaborative study highlight the opportunity to increase resilience, reduce greenhouse gas (GHG) emissions, and improve economics with the deployment of solar PV, battery energy storage, and an increase in biodigester gas production and storage to fuel the existing Combined Heat and Power (CHP) generation at the water reclamation facility. This study also found that to achieve a resilient zero carbon energy microgrid configuration, onsite biogas storage would need to be seriously considered as well as an update of the interconnection arrangement to allow the CHP system to operate at full capacity. This understanding prepares Medford to advance site planning with confidence.

CONCLUSIONS FROM THE MEDFORD MICROGRID STUDY

Fulfilling Medford's commitment to resilience and sustainability would require investment in its energy infrastructure. The financial burden of such investments would qualify these communities as worthy candidates for multiple subsidy and incentive programs from the State of Oregon, Energy Trust of Oregon, and the federal Bipartisan Infrastructure Act. The tax benefits from the Inflation Reduction Act also offer significant incentives. This study demonstrates that technically sound paths exist for a microgrid serving Medford and the surrounding irrigation district. (The irrigation district's power is delivered via the same substation to which the water reclamation facility is connected. Thus, the irrigation district could be part of the designed microgrid.) However, work needs to be extended to a feasibility study with sufficient detail to support investment-level decision-making. The modeling and analysis in this study are the first steps to a comprehensive, investment-grade feasibility study that would qualify for support from public and private sources. Such a detailed feasibility study would entail direct engagement with the electric distribution utility and regulatory authorities.

A feasibility study would include a system configuration for a single selected microgrid with a high level of detail developed using high-resolution data to inform a time series model and resulting economic modeling. Additional tasks would consider and address constructability issues, e.g., equipment specifications, circuit layouts, electrical service modifications, placement, and grid interconnection. A feasibility study would support a call for bids for construction and the identification and selection of a contractor. Once qualified bids were received, the model costing basis would be refined for final business decision and financing.

This study demonstrated what is possible and what is not. The addition of biogas production and solar panels at any scale would have positive impacts on overall carbon reduction. When paired with battery energy storage, solar becomes a valuable resilience resource that rounds out the capabilities of the biogas-fueled CHP. The modeling and analysis in the ProtoGen study demonstrates a viable path for resilient and sustainable microgrids serving irrigation districts and rural communities.

APPENDIX C – OFF-GRID SOLAR IRRIGATION, ENERGY TRUST OF OREGON, FEBRUARY 2021

Off-Grid Solar Irrigation:

Rural Farmer Implementation of Innovative Off-Grid Solar Irrigation Systems

Prepared for:

Energy Trust of Oregon

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2/10/2021

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EXECUTIVE SUMMARY

This report focuses on details off-grid photovoltaic (PV) irrigation systems with a focus on their engineering and implementation within the Southern region of Oregon. With the current and ever increasing price of electricity, an off-grid PV irrigation system becomes attractive as there is yearly expense other than maintenance and repair if needed. The initial cost of a system will easily pay off well before the warranty on the PV modules expires, typically substantially shorter. As will be shown, off-grid PV irrigation solutions exist that can easily be implemented on small to large acreage irrigation applications.

Klamath County has ideal conditions for PV power generation with over 300 days of sunshine and relatively mild summer temperatures. When considering that the agricultural season occurs when we experience the highest insolation months (suns energy in $kWh/m^2/day$) as the days are longest and the sun's elevation is high in the sky, we have an ideal situation for power production with minimal energy storage capacity. These factors in combination with 165,541 irrigated acres (2017) within the county, we have an ideal situation for off-grid PV irrigation.

The main intent in this study was to characterize existing off-grid PV irrigation. Unfortunately, two significant obstacles severely limited this intent; COVID-19 pandemic and customer privacy concerns lead to only one active system being characterized. As a result, this report focuses on the system design, both PV pumping and irrigation method, the initial costs of a system and the yearly electricity cost savings.

For example, a \$50,000-75,000 investment per irrigation pivot in an off-grid PV pumping system would equal the electricity cost over 20 years without factoring in future rate increases. With many PV modules warrantied for 30 years currently, this would put between \$25,000 and \$40,000 back into the farmers pocket. Of course, this does not factor in a new installation where the cost to bring this 3-phase power sits between \$50,000 and \$80,000 per ¼ mile.

Secondly, many of the crops grown on what is called the market farm currently use sprinkler irrigation. Sprinkler irrigation waters all of the field at a water efficiency rating of around 40-50%. Drip irrigation only waters the desired plants at a 96-98% water efficiency. Every gallon of water pumped takes electricity, hence increasing the water efficiency and only irrigating the desired plants leads to significant water savings and reduction in energy costs. The sprinkler irrigation of crops could be replaced by an off-grid drip irrigation system with significant environmental and financial benefit. Additionally, there has been a significant increase over the last few years in the cultivation of hemp and marijuana in seasonal greenhouses where off-grid PV drip irrigation systems are an ideal solution considering the portability of such systems.

In summary, off-grid PV irrigation systems have significant potential in agriculture. The initial costs are similar to significantly lower than the grid tied system yet without the yearly electricity expense. For many crops, water savings can be realized as a secondary benefit. It takes electricity to pump every gallon of water; if you don't have to pump it, you save.

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INTRODUCTION

This report explores the usage of off-grid PV irrigation systems at farms located in the Southern region of Oregon. Additionally, it details the engineering behind the system in order to provide the reader comprehensive knowledge on the subject. The introduction discusses the project description and purpose, scope of evaluated material, and report format.

Project Description and Purpose

This report analyzes the engineering of off-grid PV irrigation and lightly establishes its usage on Southern Oregon farms. The design details, as well as challenges, are examined in order for the reader to develop a great understanding for PV irrigation. As the need for adaptable green energy resources continues to increase along with electricity costs, off-grid PV irrigation allows green energy to be accessible for rural farm landscapes. The purpose of this paper is to provide a report on off-grid PV irrigation systems and their usage within rural farming, with Southern Oregon as an example.

Scope of Evaluated Material

This report discloses details to the engineering of off-grid PV irrigation systems. These details will include specifics on the components of the PV irrigation systems, off-grid design, and challenges posed. Although the intent of this study was to investigate multiple off-grid PV irrigation systems, due to COVID-19 and privacy of customers for local PV install companies, only one currently operating system will be discussed. Examples of other system designs will be shown including cost estimates. System maintenance, manufacturers of off-grid PV irrigation components, and the irrigation control systems used are outside the scope of this report.

Report Format

This report includes the sections:

- Background Information: Off-Grid PV Irrigation
- Engineering/Development Concepts of Off-Grid PV Irrigation Systems
- Lake/Klamath County Irrigation Research
- Conclusion
- References

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BACKGROUND INFORMATION: OFF-GRID PV IRRIGATION

It is first important to understand the general construction of an Off-Grid PV Irrigation system. The generalized flow of a PV irrigation system follows that of Figure 1, shown directly below. An off-grid PV irrigation uses solar energy harnessed by PV modules for powering a water pump that leads to the water piping system for irrigating desired vegetation [1].

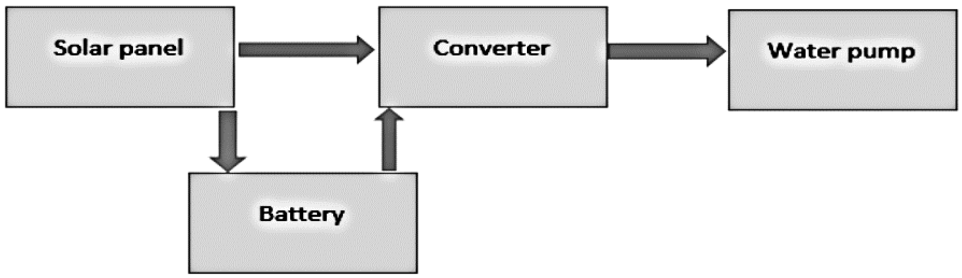

Figure 1 General Off-Grid Solar Irrigation Block Diagram

The traditional water pumps used are powered by the local power grid or a fuel source. The total area or number of plants to be watered and frequency of an irrigation cycle determines the size of system needed which can vary from a simple, small DIY system to an elaborate 3-phase, high horse-power (hp) systems. When looking at off-grid systems, the traditional systems are powered by gasoline, kerosene, or diesel-powered water pumps [2]. While these pumps allow for greater flexibility and a cheaper build, they rely on fuel availability, maintenance/refueling hours, cause negative environmental impacts, and have a higher overall operating cost.

With solar energy being considered the, “most abundant source of energy in the world”, it is not only an off-grid source solution for its availability but also due to inherently being, “an environmentally friendly form of energy” [3]. The lack of obstructions to reduce sun exposure and average of 300 days of sun on most farmlands further increase the potential energy obtained. An economic study conducted by Utah State University Applied Economics Associate Professor Kynda R. Curtis, found that Photovoltaic powered irrigation systems led to an increased annual farm net return [4]. Providing farmers the opportunity to increase their overall economic return while also using a cleaner energy source to power their irrigation systems.

Since the introduction of PV powered irrigation systems there has been three distinctive generations of pumps. The current generation of pump systems are narrowed down to three types that will be further discussed within this report.

ENGINEERING/DEVELOPMENT CONCEPTS

While the design of an off-grid PV irrigation system can be generalized to the block diagram shown in Figure 1, the system design is categorized into a) gravity or b) direct as shown in

Figure 2 with further sub-variations for each. Gravity based uses gravity to provide low-pressure, less than 10psi, irrigation flow to the crop primarily used for drip type emitters that delivers water directly to each plant only. Direct use systems can supply a range of pressure up to around 70psi and can be used for spray emitter/sprinkler systems.

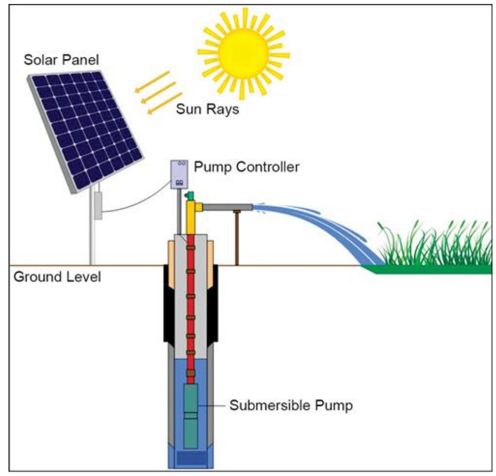

Figure 2 PV powered irrigation system

Two general categories of PV powered irrigation systems. Left is a gravity system. Right is a direct application system.

Off-Grid PV Irrigation Designs

The usage of Photovoltaic (PV) pumping has been proven by multiple studies to be, “one of the most promising applications of solar energy” [5]. Through its development, there has been three distinctive generations of innovation for the pumping systems. While the older generation pump designs are still used and are typically required for high volume applications, they less common for smaller volume systems due to efficiencies and capital costs. The first generation of PV pumping systems used centrifugal pumps typically driven by AC motors or DC powered motors being less common. These types of pumps are typically seen for applications requiring greater than 1hp. This first generation, specifically AC motors, proved to have long-term reliability yet with efficiencies ranging from 25% to 35%. The DC motors of this generation proved to be less reliable with increased maintenance due to having a “brush” design to transfer the electricity to the rotating windings. The brush is a wear part that periodically needs replacing.

The second generation used three pump designs: positive displacement, progressing cavity, or diaphragm pumps. These pumping systems showed great innovative strides as they required low PV input power, low capital costs, and had high efficiencies of up to 70%, yet have lower

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volume capability as compared to centrifugal pump heads. These pumps can have either AC or DC motors and are typically brushless.

The third, and most recent, generation of PV pumping systems uses electronic systems to

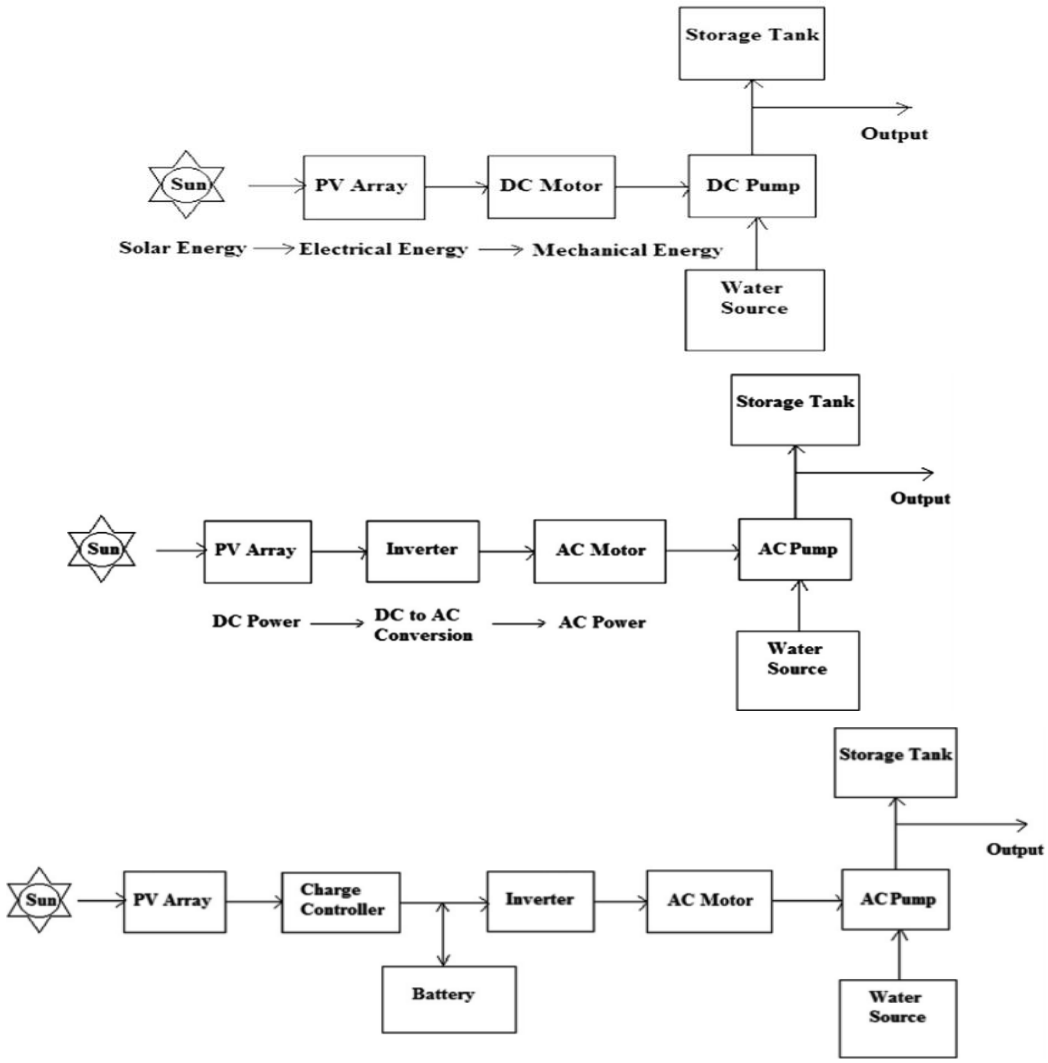

Figure 3 Current Solar Water Pumping System Configurations

increase the output power, performance of the system, and overall efficiency. These electronic systems include controllers for the storage tank levels, pump speed, and maximum power point tracking ultimately optimizing the water usage. This in combination with the ever-increasing efficiency of PV modules leads to overall high efficiencies of PV irrigation systems. In Figure 3, three types of current configurations of direct coupled DC and AC PV water pumping systems is illustrated. The top block diagram is the depiction of a direct coupled PV DC water pumping system with no energy storage capability. This system is an “uncontrolled power” system where the motor speed is controlled by the voltage of the PV array; the higher the voltage, the faster the pump speed. The voltage of the PV array varies with the illumination intensity of the sun

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and only operates during daylight once there is sufficient voltage to overcome the electro-mechanical resistance of the motor/pump.

The middle block diagram uses a PV inverter to convert the DC voltage output of the PV array to an AC voltage to drive the AC motor/pump. The inverter is designed to provide a constant power output once the minimum turn-on input power is surpassed and provide a constant power to the motor. Again, this system will only operate during daylight as there is no energy storage in the system.

The bottom block diagram utilizes battery charge controller and storage to enable 24 hour operation depending on the energy storage size, along with an AC motor and pump. Alternatively, to drive a DC motor and pump, the DC to AC inverter can be replaced with maximum power point tracker (MPPT) to provide optimal electrical output for battery charging/discharging (the battery is connected via dedicated terminals on the MPPT device) and DC motor/pump operation.

Irrigation Methods

In addition to considering what PV water pumping system is desired for an off-grid PV irrigation system design, one must also determine what type of irrigation system would be the most

Figure 4 Furrow Surface Irrigation

beneficial for their crop type. This irrigation system will be attached to the output of the water pump and has great influence on the application efficiency and economic return of the overall system [6]. The most relevant factors to assist in determining the desired irrigation type includes crop and soil type, topography, water availability, and weekly water needs of the crop. Water application method can be classified into three categories: surface flood, spray/sprinkler and drip. The most common forms of surface flood irrigation systems are contour, border, and furrow irrigation. Furrow irrigation method (Figure 4) is the most frequently used for row crops irrigation. This traditional irrigation method, although relative simple to implement, has the highest total water use with the least efficiency for row crop agriculture.

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Sprinkler or spray method has higher irrigation efficiency and lower total water needs as compared with surface flood methods. This type of irrigation uses either traditional impact sprinklers or a spray head as shown in Figure 5. These systems require pressurized water to operate that ranges from approximately 20psi to 75psi. The spray is designed to uniformly apply water across a circular area a set distance from the head. Depending on the pressure and head design, the wetted circle radius ranges from 6ft to 65ft in general with a large range of application rates available.

Figure 5 Sprinkler Irrigation

Drip irrigation can be classified into two categories: a) drip tube and b) drip tape. A drip tube system consists of a semi-ridged poly tube where individual emitters are inserted where desired. Emitters can be select for a range of flow rates from 0.1gal/hr to 2gal/hr. The tube is placed directly on top of the soil or raised to a specific height, depending on the crop type. A drip tape is a flexible flat tube that expands into a oval or circular cross-section when charged

Figure 6 Drip Tape Irrigation System

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with water. Drip tape has emitters that are formed during the manufacturing process. Drip tape rolls can be purchased with emitter spacing from 4 inches to 48 inches with flow rates from 0.1gal/hr per 100ft to 1.5gal/min per 100ft. Drip tape can be laid directly on the soil, raised to a specific height or buried in the soil to a set depth. Buried drip tape has the highest irrigation efficiency as the precise amount of water is applied directly to the roots eliminating evaporative loss and can lead to reduced weed competition.

Specific Components of Irrigation Systems

Within the entire irrigation system there is a multitude of specific components that must be determined to optimize the overall system when combined. These components include:

- Solar panels/modules
- Pump type
- Motor type
- System support structure
- Tracking mechanisms
- Electrical interconnections
- Earthing Kit
- Plumbing (irrigation type)
- Water Supply
- Water Storage System
- Etc.

The first step in the system design is to determine the nature of the water source: surface (canal, pond, storage tank) or subsurface (shallow or deep well). Secondly, one must determine if the final stage in delivery of water to the crop will be gravity or pressurized. For example, a gravity system with a canal as the source would require a surface type pump and piping to a tank that is at a sufficiently high elevation from the crop to be irrigated (hill or raised support structure) to create the minimum pressure needed by the application method. Typically, drip type irrigation is used as each foot of elevation results in 0.423psi gain hence, the needed elevation for pressures above 20psi (47ft) is in many cases impractical.

To determine what specific components are needed by the system, calculations can be conducted to determine necessary parameters. Beginning with the equation for Hydraulic energy:

$$\boldsymbol{E_h = \rho \times g \times V \times TDH}$$

One can determine, in $^{kWh}/_{d}$, how to properly supply a volume (*V*) of water in m^3 at total dynamic head in meters (*TDH*) considering the water's density (*ρ*) and acceleration due to gravity (*g*). The TDH is the sum of the static head in meters and friction losses in meters. Additionally, one can determine the required power from the PV photovoltaic array by using the equation:

$$\boldsymbol{P_{pv} = \frac{E_w}{I_T \times \eta_{mp} \times F}}$$

Where the I_T represents the average daily solar irradiation, in $^{kWh}/_{m^2 day}$, incident on the plane of array with *F* being the array mismatch factor. The n_{mp} utilized within this equation is the daily

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subsystem efficiency. Next one can calculate the amount of water pumped daily by finding the value in m^3 using the equation:

$$V = \frac{P_{pv} \times I_T \times \eta_{mp} \times F}{\rho \times g\, TDH}$$

Through the process of variable association, it is determined the numerator possesses many variables from the equation of power required from the array while the denominator has many from the equation of hydraulic energy. All of these variables are used together to determine the volume of water pumped. To determine the efficiency of the motor pump (n_{mp}) one would divide the hydraulic energy output of the system by the input energy [5].

Once an idea for the general parameters of the irrigation system are found, the PV water pumping system can begin to be constructed component by component. The PV technology converts sunlight into electricity to charge a battery and/operate a pump. A determination must be made on the electrical system type, DC or AC, for the proper selection of the PV interface. This is largely determined by the pump needed for the application as discussed below. The interface would either be a charge controller/MPPT tracker or inverter for DC and AC systems, respectively.

Pump Selection

Pump selection is arguably the most significant decision in the system design bound by the total volume needed to water the field in a single cycle (TV_{cyc}) and frequency of cycles (F_{cyc}). Both parameters are determined by the crop type and the application method for the month during the growing cycle with the greatest irrigation needs for the specific climatic conditions at the location. This typically occurs in the mid to late summer months. Once these parameters are determined, then the gallons per minute (gpm) and water pressure requirements are calculated. Water source directly dictates the pump mechanical design. For well applications, there are two options: in-well submersible and surface. For in-well submersible, the pump is cylindrical to fit into the well bore-hole and located below the water level of the well. The depth below the water level is determined by the well recovery rate. Well recovery rate is simply how rapidly the water flows into the well from the surrounding strata as the water is extracted by the pump. Well recovery rate also determines the maximum pump flow rate. There are a multitude of impeller designs and horse-power (hp) ratings for in-well pumps to meet the depth of the well and flow rate desired. Surface pumps for well applications can be broken down to two styles: shallow well pumps than can lift the water up from a maximum depth of 25ft, and jet pumps that can fit applications down to approximately 50 ft.

There is an inverse relationship between gpm and psi (or feet of head). As more pressure is needed, flow rate is reduced. This relationship is illustrated in a “pump curve” for each pump. An example of a pump curve for a comparable DC pump and AC pump is shown in Figure 7.

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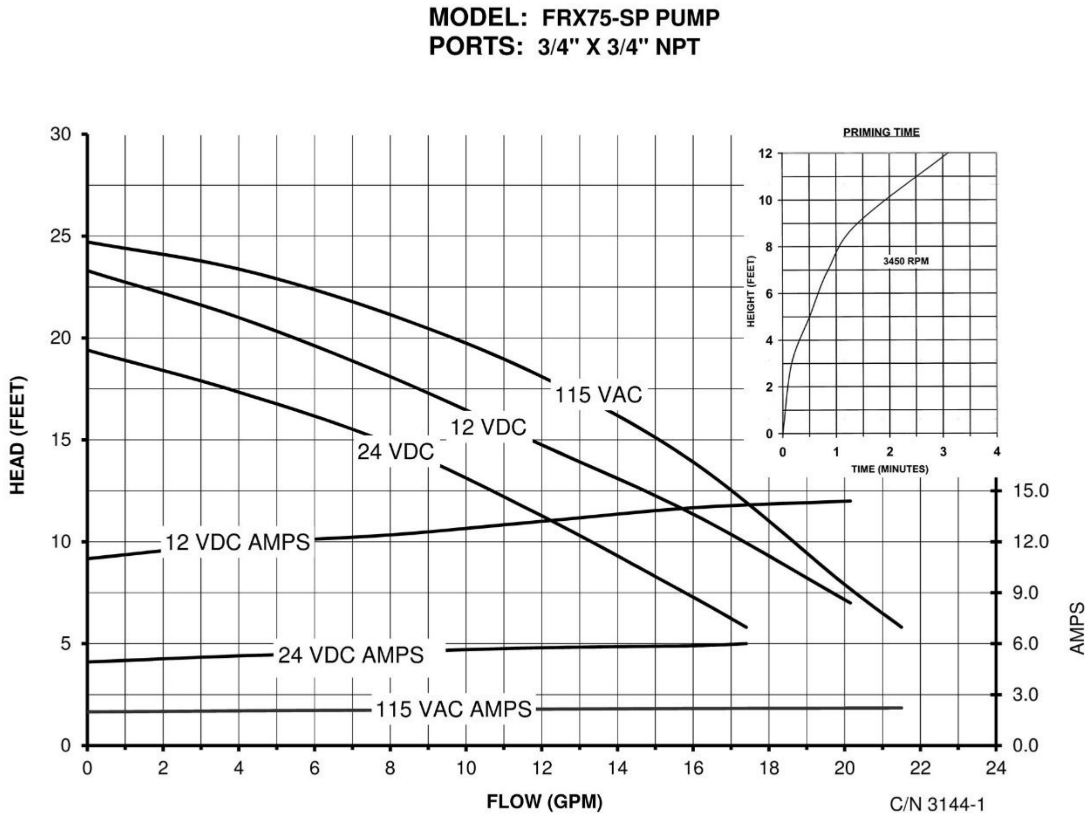

Figure 7 Example Pump Curve

Pump Curve for an AC and DC surface pump. The horizontal curves correspond to the right axis (Amps). The upper downward trending curves correspond to the left axis (Head in feet). To convert: 1 foot of head equals 0.4334 psi.

The capacities for volume and pressure needed are easily satisfied by an AC pump due to available range in hp from ¼ hp to several hundred hp. As previously stated, centrifugal pump heads are predominately used for surface pumps with the upper bounds in efficiency of 35%. This loss in pumping efficiency requires a larger, more expensive electrical system. For example, a 1hp AC pump requires 746W (assuming no losses in the electrical system) to supply 55gpm at 10 psi or 17gpm at 40psi. With respect to an off-grid PV power source, a DC to AC inverter is needed. If the system is needed to operate when the PV array is not producing sufficient power (from 4pm till 9am typically), an energy storage system is needed. The energy storage system would need to have a minimum capacity of 120amp-hours to support 17 hours of battery only power. Amp-hours is the number of hours the battery can supply 1amp of current. The PV array would need to be increased in size to both operate the pump and fully charge the energy storage system simultaneously and a charge controller is required in addition.

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The DC pump market has largely been confined to lower flow, low psi applications such as drip irrigation. Recently, efforts are being made to advance/expand the DC pump options [7]. Commercially available DC pumps are available flow capacities up to 20gpm with open flow (0psi) or 6gpm at 10psi with a power need of around 144W. For a DC based system a charge controller would be needed to optimize the power delivered from the PV array. Due to the lower power requirements a smaller PV array is needed along with the energy storage capacity.

Photovoltaic System

There are a multitude of photovoltaic modules commercially available with different technologies, power ratings and form-factor. Technologies include monocrystalline, multicrystalline (also named polycrystalline by some manufacturers) and thin-film. Both monocrystalline and multicrystalline are available in standard, sunlight is only absorbed on the front surface, and double sided (PERC) which captures additional light on the backside of the module. Thin-film is generally designed for utility scale generation facilities or building integrated applications due to the form-factor, lower efficiencies and not well suited towards off-grid applications.

Monocrystalline modules have higher theoretical efficiency than multicrystilline and the method of measuring the electrical performance of the module is to illuminate the module with perpendicular incident illumination, hence biasing the measurement towards monocrystalline due to the surface texture of the individual cells. This leads to typically higher cost in dollars per watt for monocrystalline modules. In fixed mount or 1-axis tracking applications the power produced is equal or higher for multicrystilline as it is able to capture incident light from significantly greater angles and diffuse light. Once the farmer has determined the panel they feel comfortable investing in, calculations must be made to decide the required PV array size to provide the required energy to supply the system. This is accomplished using the PV array power required equation as previously shown. Multiple software programs exists for performing the array sizing calculations [7,8,9,10]. An appropriately sized charge controller/MPPT[1] for DC systems to connect with the DC pump and energy storage (optional). For an AC pump an inverter is needed to interface the PV array to the pump, yet if. If energy storage is desired then a charge controller is additionally needed.

Array sizing also depends if system operation is desired when the PV array is not generating sufficient energy such as late evening, nighttime or 24 hour operation. This then would need an energy storage capability which currently is limited to traditional battery technologies. Traditional battery technologies include Lithium-ion, Lead Acid, Nickel-metal-hydride to name a few. With recent advances in hydrogen fuel cells and flow-cell batteries, the author believes we will see these technologies move into the off-grid irrigation space. One can imagine

[1] Charge controllers are available in Pulse-Width Modulation (PWM) or Maximum Power-Point Tracking (MPPT). MPPT charge controllers are considered electronically superior to PWM controllers due to the quality of the output power and reliability.

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implementing a fuel cell as the energy storage medium with an electrolysis unit that produces the hydrogen fuel from the irrigation water.

Sizing of the energy storage system using batteries is relatively straightforward. The instantaneous current requirements of the irrigation pump and other electronics is multiplied by the number of seconds of operation, then divided by 60 to determine the number of amp-hours of storage required. A battery or multiple batteries are then selected to fit the application.

System Advantages and Challenges

The implementation of a green energy resource by the agricultural industry is an enormous positive advancement for cleaner ecosystems in America. Within America, the, "agriculture, food, and related industries contribute $1.053 trillion to the U.S. gross domestic product"; ultimately, displaying how influential this sector is on the United States [11]. Aside from the environmental advantages of these systems, farmers can also receive government incentives such as tax deductions [12].

For PV pumps in particular, there are distinct advantages that include:

I. Opportunity: Provides irrigation pumping abilities to farms distant from their local grid.
II. Low operating cost: Due to no fuel required for the pump, such as electricity or diesel, the operating cost is minimal.
III. Low maintenance: A well-designed system requires little maintenance beyond cleaning the panels with components possessing decent lifespans.
IV. Harmonious with nature: Provides maximum water output for efficient and conservative watering for crops.
V. Flexibility: The PV panels do not need to be directly next to the well.

These advantages described above prove the efficiency and economic positives associated with automating the agriculture sector with off-grid PV irrigation systems [3]. The usage of an off-grid PV irrigation system carries many positives, as well as challenges due to the system's development still being innovated.

General disadvantages and challenges to these systems can include:

I. Low Yield: PV pumping's maximum capacity can be considered low.
II. Variable Yield: The water yield of the PV pump can vary due according to the sunlight without energy storage capability.
III. Theft: Dependent on the location of the farm, theft of these technological components could be an issue.

In addition to these few system challenges, there are challenges with deterioration of system technology to include the PV panels. Depletion in PV performance can be directly attributed to, "important environmental conditions", which include, "insolation, ambient temperature, and

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wind speed" [3]. More in-depth, the condition of the PV cells on the PV panel can experience degradation of efficiency at approximately 1% per year due to, "humidity, temperature, system bias effects, and solar radiation" [5].

A study conducted by scientists S.S. Chandel, Nagaraju Naik, and R. Chandel evaluated a multitude of PV water pumping systems varying from domestic to irrigation usage in order to conclude on research findings. These research findings, Tables 1 and 2, introduced diverse results to consider when constructing a system [5].The irrigation studies shown within Table 1 provide results to the usage of detection and tracking technologies within the PV irrigation system. Additionally, it details important considerations to take prior to constructing an irrigation system so that it runs with the highest system efficiency for the most lucrative return. The authors of this review prioritized, within their research of various studies, informing the audience on PV irrigation system optimization for reduced economic commitment and environmental impact. Particularly to reduce large quantities of water going to waste through poor irrigation techniques. The second table from this review, Table 2, changes from location determining the study type to categories such as, "economic viability", "economic analysis", "rural water supply", etc. This allows for the research findings to focus solely on explicit output results.

Table 1 PV Water Pumping System Performance Evaluation Study Summaries

The table below discloses the research findings of multiple experimental studies conducted by scientist

S. no.	Reference	Country	Application	Research findings
1	Gad [14]	Egypt	Domestic	Computer simulation program is used to simulate the performance of a proposed PV water pumping system.
2	Katan et al. [15]	Australia	Domestic	System efficiency increases with MPPT and sun tracker.
3	Loxsom and Veroj [16]	Thailand	Irrigation	Algorithm is developed to estimate the water pumped as per insolation.
4	Khan et al. [17]	Bangladesh	Rural water supply	System efficiency is increased by adding DC–DC buck converter for a direct coupled PV water pumping system.
5	Mokeddem et al. [18]	Algeria	Irrigation	System efficiency increased by orientation and sizing of PV array and motor pump system.
6	Kou et al. [19]	USA	Domestic	Predicted monthly water pumped by a system within 6% of TRNSYS prediction based on hourly data.
7	Hadj Arab et al. [20]	Spain	Domestic	Optimized a proposed PV water pumping system by studying individual requirements with a simulation program.
8	Pande et al. [21]	India	Irrigation	Reported 6 years pay-back period including subsidies on PV modules.
9	Mohanlal et al. [22]	Egypt	Irrigation	System efficiency is increased up to 20% by manually tracking thrice in a day.
10	Alghuwainem et al. [23]	Saudi Arabia	Irrigation	Self excited induction generator utilization avoids need for matching devices and tracking systems.
11	Benghanem et al. [24]	Saudi Arabia	Irrigation	Electronic array configuration should be included in order to match maximum power points of PV array with pump
12	Atlam and Kolhe [25]	Turkey	Domestic	System performance and efficiency can be improved by matching the output characteristics.
13	Setiawan et al. [26]	India	Irrigation	Two important design aspects for PV water pumping system are identified; analyzing piping system to determine the type of pump to be used and power system planning.
14	Reddy and Reddy[27]	India	Domestic	Configuration of the photovoltaic system can be improved with dynamic models for inverter, single phase induction motor and neural network based maximum power point tracking.

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Table 2 PV Water Pumping System Usage Findings

The table below discloses the research findings of multiple experimental studies conducted by scientist concerning the economic and environmental aspects of PV water pumping systems.

S. no.	Reference	Country	Study type	Research findings
1	Odeh et al. [60]	Ireland	Economic viability	Mismatch between water demand and supply patterns have a major effect on economic viability of the PV pumping.
2	Jamil et al. [61]	India	Techno-economic analysis	Payback period of less than 4 years with huge savings over 16 years.
3	Hamidat [62]	Algeria	Economic analysis	PV surface pumps to supply water can contribute to socio-economic development in remote Sahara regions.
4	Kaldellis et al. [63]	Greece	Economic and environmental analysis	PV pumping systems are economical viable options for water consumption needs of remote communities.
5	Purohit and Kandpal [64]	India	Financial evaluation	PV pumping systems are viable option when sufficient incentives are provided by government.
6	Foster and Hanley [65]	Mexico	Economic analysis	Economically viable PV water pumping systems gained foot hold and changing the face of water pumping in Mexico.
7	Kumar and Kandpal [66]	India	Environmental and economic analysis	Capital cost of PV pump, its useful life, price of fuel substituted, and discount rate on the unit cost of CO_2 emission mitigation are of importantance for solar pumping promotion
8	Rezae and Gholamian [67]	Iran	Economic analysis	Considerable savings are observed in PV water pumping system as compared to conventional systems.
9	Foster et al. [68]	USA	Rural water supply	Investment payback for PV water pumping systems is averaged about 5–6 years
10	Fedrizzi et al. [69]	Brazil	Irrigation	Negligence of local specificities and technology transfer methods cause PV water pumping systems failure.
11	Meah et al. [70]	USA	Rural water supply	PV water pumping systems reduce CO_2 emission considerably over its 25-year life span.

LAKE/KLAMATH COUNTY APPLICATION

The application of off-grid PV irrigation has become a desirable resource within the region of Southern Oregon. Experimentation has found that farmers of arid regions experience an increase crop yield by roughly 300% when off-grid PV irrigation is used for motorized pumping systems [1]. A study by the USDA examined the trends in energy for pumping irrigation water for the United States [14]. From 2003 to 2013, the number of irrigated acres by electricity increased from 24,000 acres to 33,000 acres (Figure 8). The electricity expense to irrigate these

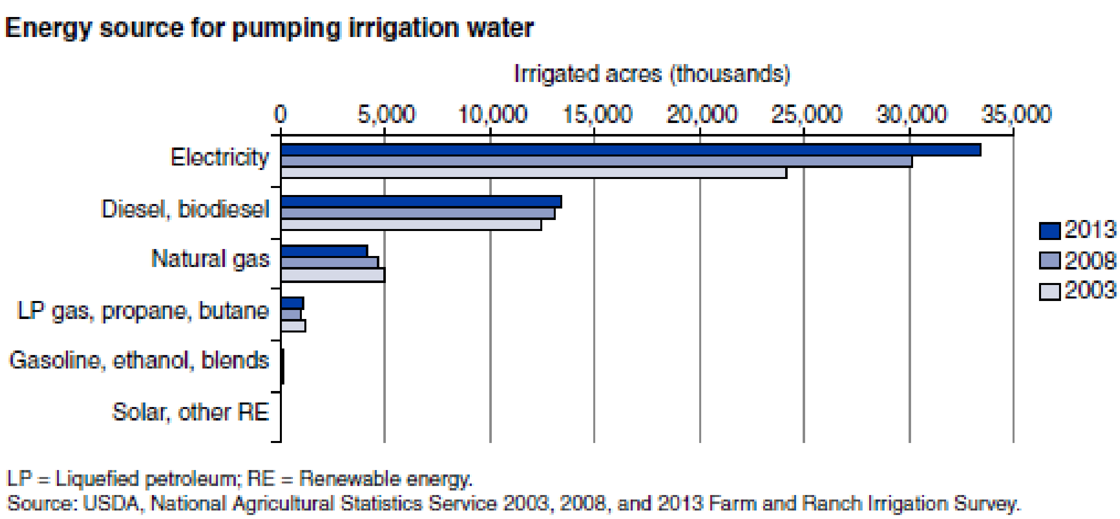

Figure 8 Energy Source for Pumping Irrigation Water in the US

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acres grew by 29% from $39/acre in 2003 to $55/acre in 2013 (Figure 9). Although PV and other renewable energy technologies are shown in the table, there appears to be either no acres irrigated by these means, or this category was not investigated.

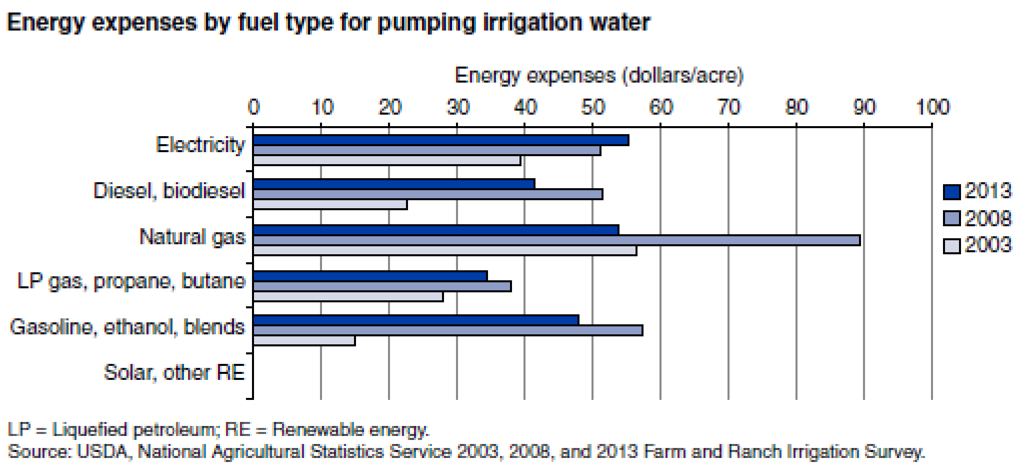

FIGURE 9 ENERGY EXPENSE BY FUEL TYPE FOR PUMPING IRRIGATION WATER IN THE US

A study conducted by Sandia Laboratory scientist, titled *Preliminary Economic Analysis of Solar Irrigation Systems (SIS) for Selected Locations* [13}, evaluated the validity of off-grid PV irrigation usage by farmers in Southeastern Oregon. As shown in Figure 10, the scientists determined Oregon as the number 2 state in the entire nation for energy weight by on-farm surface water pumping and number 9 for both surface and ground water pumping. With well sources being the primary water storage system for PV irrigation systems, this surface water

	On-Farm Surface Water Pumping Only	On-Farm Groundwater Pumping Only	On-Farm Pumping of Ground or Surface Water
1	Washington	Texas	Texas
2	Oregon	California	Arizona
3	Mississippi	Arizona	California
4	Texas	Nebraska	Washington
5	Montana	Kansas	Nebraska
6	Nebraska	Idaho	New Mexico
7	South Dakota	New Mexico	Kansas
8	California	Hawaii	Idaho
9	Arkansas	Oklahoma	Oregon
10	Louisiana	Washington	Hawaii
11	Utah	Nevada	Mississippi
12	Florida	Arkansas	Oklahoma
13	Wyoming	Colorado	Colorado
14	Nevada	Utah	Nevada
15	North Carolina	Oregon	Arkansas

Figure 10 Energy Weight Ranking of States for Irrigation Pumping

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statistic started Southern Oregon's nudge towards off-grid PV irrigation. In 2019, electricity sales in Lake County for irrigation amounted to 18,341,386kWh, or 10% of the total electricity consumed within the county. Lake County agricultural operations predominately consist of livestock and hay operations with little specialty or row crops with an annual market value of $93895,000, Appendix A. Klamath County has a significant mix of specialty and row crops such as potatoes, mint, strawberry starts, etc. in addition to livestock and hay production with an annual market value of $192,598,000, which is also the largest market value (more than double the next closest county) in Southern Oregon. With this context, electricity for irrigation in Klamath County is likely at least double Lake County's consumption.

Energy cost per acre for irrigation has been studied for Oregon and the Klamath Basin [15] and a second, more recent publication on the Klamath Project [16]. In these studies the estimated cost of electricity per sprinkler irrigated acre across Oregon is between $38 and $60 with the costs in the Klamath Project are estimated at $45 per acre. Quantifying the electricity charges over 20 years[2] for the off project entities equates to roughly equates to $740 to $1200 per acre. A center pivot irrigation system with a length of 1000ft has an average coverage of approximately 80 acres which equates to a 20 year electricity cost of $60,000 to $97,000 (without accounting for frequent rate increases). For a new electric service (240V single-phase and 480V 3-phase have approximately 10-15% difference in costs) installation, the costs range between $50,000 and $80,000 per ¼ mile. Hence, a 20-year total cost for a new ¼ mile electric service results in an investment of $110,000 to $177,000 for the irrigator. The report section following titled Costing of Various PV Pumping Systems provides estimates of various sized off-grid PV irrigation systems.

Interviews

In light of the current national pandemic, COVID-19, and concern for an infringement on the confidentiality of their farm, farmers around the region were reluctant to meet and disclose specifics of their off-grid PV irrigation systems. That said, local farmland owner and author of this report, Mason Terry, has provided some insight to the off-grid PV irrigation system located on his farm. The following is the questioner that was developed to full characterize the off-grid PV irrigation system as used by the specific farm.

1. Property owner/Farmer
2. General description of the system
3. Location
    a. Specific location
        i. County/demographic (ArcGIS evaluation)
    b. Where on the farm is the system located
        i. Acreage coverage of system
        ii. Type Crops/livestock within the covered area

[2] 20 year timeframe is chosen to allow comparison to a minimum PV module warranty term. Typically, PV modules last significantly longer with several manufactures providing at least 30 year warranty.

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iii. What is the water source

4. Technical requirements for their specific system
    a. Pump
        i. Type
        ii. Size capacity
    b. Power source (Photovoltaic System)
        i. Type
        ii. Capacity for powering pump
        iii. AC vs DC
    c. Power Storage System
        i. Type
        ii. Location
        iii. Issues associated
    d. Special technical needs (specific to their system)
5. Requirements (related to Irrigation regime)
6. Permit requirements
7. Annual cost implications
    a. PV components of the system based off pump size
    b. Pumping components based off pump size
8. What is the operating history of the system
    a. Timeframe for development of the system
    b. Modifications to the system
    c. Seasonal implication of the system
        i. Time of use information
    d. Challenges/Lessons learned

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Crater Lake Farm Questioner

1. Property owner/Farmer

   Crater Lake Farm, Mason Terry owner/operator
2. General description of the system

   The system is designed for buried drip tape irrigation of organic garlic in machine shaped earthen raised beds. Each 120 ft row of garlic has 5 plants across per row with rows spaced 6 inches apart down the length. 2 buried drip tapes per bed with an emitter flow rate of 0.45 gal/hr/100ft with emitter spacing of 6 in. A maximum of 24 beds (approximately 28,000 plants) can be watered per week. Water is supplied by two tanks, 3000gal and 4000gal.
3. Location
   a. Specific location
      i. County/demographic (ArcGIS evaluation)

         667 Day School Rd, Chiloquin OR 97624; 42°30'14.6"N 121°53'26.9"W
   b. Where on the farm is the system located
      i. Acreage coverage of system

         The system can irrigate approximately 28,000 garlic plants over ¼ acre every week.
      ii. Type Crops/livestock within the covered area

         Organic garlic
   c. What is the water source

      Water is supplied via irrigation district and stored in two tanks, 3000gal and 4000gal which is the pumps supply. Manual sight gauges on both pumps to determine quantity of water stored.

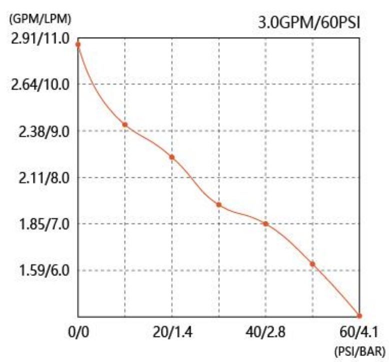
4. Technical requirements for their specific system
   d. Pump
      i. Type

         SeaFlow model 54 (pump curve below)
      ii. Size capacity

         Open flow 3.0 gal/min

         60psi max pressure

         12V at 12A (144W)



   e. Power source (Photovoltaic System)
      i. Type

         Two 240W multicrystalline modules connected in parallel, 480W total. Y&H EPever MPPT 30A charge controller.
      ii. Capacity for powering pump

         480W (modules) – 144W (pump) = 336W for charging batteries at 1-sun illumination.
      iii. AC vs DC

         DC system

   f. Power Storage System
      i. Type

         Sealed lead-acid gel cell, two at 33ah = 66ah storage capability.
      ii. Location

         In pump shed
      iii. Issues associated

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None

g. Special technical needs (specific to their system)
   Inline fertigation injection system.

5. Estimated cost of the system (PV system, pump, immediate plumbing/valves from water source to main distribution lines, tank, etc)
   Approximately $750
   With the amount of use to date the energy produced by the PV system has paid for itself in 4 years.

6. Requirements (related to Irrigation regime)
   Hand operated three level (dry, moist, wet) conductivity meter is used to determine rough soil moisture. Soil is kept in damp state.

7. Permit requirements
   N/A

8. Annual cost implications
   h. PV components of the system based off pump size
      none
   i. Pumping components based off pump size
      None

9. What is the operating history of the system
   j. Timeframe for development of the system
      A few days of work to assemble the PV + pumping unit
   k. Modifications to the system
      none
   l. Seasonal implication of the system
      i. Time of use information
         Over 3 season of system use, approximately 43kWhr have been produced/consumed for irrigating. Irrigation typically starts mid May through early July with amount/frequency dependent on soil moisture.
   m. Challenges/Lessons learned
      Learning to determine the soil wetting profile across the bed. Number of rows that can be watered simultaneously. Have moved from 5 to 4 plants across a bed to ensure uniform watering to each plant.

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Costing of various PV pumping systems

The cost of irrigating a crop can significantly impact the farm due to the $38 to $60 per acre per year for electricity. In Table 3 estimated PV system sizes including energy storage are listed with associated cost estimates. System costs do not include the mechanical racking for the PV array, installation or other balance of system components. The top two DC drip systems are an ideal fit for greenhouse cultivation of crops. Of note is the system on the last row in the table. This system is designed to meet the water supply needs for both flow and pressure of a typical irrigation pivot that irrigates approximately 60 acres.

Table 3 PV System Estimated Size for Off-Grid Irrigation

Application	PV and Energy Storage Size Estimate (assumes 24/7 operation, mechanical structure/mounting excluded)	Aproximate cost
	DC	
Small drip, 3.3 GPM	600W, 30A MPPT, 70ah battery	$ 750.00
Large drip, 8GPM	800W, 40A MPPT, 100ah battery	$ 1,000.00
12/24V sprinkler, 20 gal/min	1.2kW, 60A MPPT, 200ah battery	$ 1,300.00
48V sprinkler, small, 5-15 GPM	2kW, 120A MPPT, 200ah battery	$ 1,800.00
48V sprinkler, large, 15-35 GPM	3kW, 120A MPPT, 400ah battery	$ 2,800.00
	AC (upper bound in cost)	
120/240V, 70 GPM 2 HP	5kW, 200A MPPT, 800ah battery, medium inverter	$ 6,000.00
120/240V, 160 GPM 5 HP	12kW, 200A MPPT, 1200ah battery, large inverter	$ 11,700.00
480V, 3-phase, 10 HP, 200 ft. Max. Head, 300GPM open flow, 100GPM @ 50 psi	22kW, 400A MPPT, 1600ah battery, small 3-phase inverter	$ 24,000.00
480V, 3-phase, 25hp, 1000GPM open flow, 250GPM @ 50psi	55kW, 600A MPPT, 2400ah battery, medium 3-phase inverter	$ 50,000.00

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CONCLUSION

Klamath County has significant agricultural operations with $192.6 million in goods sold yet with $175.9 million in farm expenses, leaving $26.8 million in farm income with an average net cash income per farm of $26,643. In the County there are 165,541 acres irrigated which is 34% of all land in farms. Calculating the 20 year electricity expense for irrigated acres, not factoring in frequent rate increases, results in $125.8 million to $198.6 million. This is a farm expense that can be greatly reduced by an investment into an off-grid PV irrigation system. A $50,000-75,000 investment per irrigation pivot would equal the electricity cost over 20 year without factoring in future rate increases. With many PV modules warrantied for 30 years currently, this would put between $25,000 and $40,000 back into the farmers pocket. Of course, this does not factor in a new installation where the cost to bring this 3-phase power sits between $50,000 and $80,000 per ¼ mile. There is increasing activity in the development of larger DC irrigation pumps to address the market need of an off-grid PV system. We will soon see new center pivot installs that will have such an off grid PV system supplying that water to irrigate the crops. One can envision that the entire pivot could be off-grid PV powered; mount the PV array across the top span of the pivot itself!

For smaller applications, especially as we have seen a dramatic increase in drip irrigation for greenhouse cultivation, an off-grid PV system would provide all of the irrigation energy needs for a reasonable system cost with no need to bring in grid power, a substantial savings in upfront costs and lifetime costs. As many of the smaller farms rely on DIY solutions, an off-grid PV system can be easily assembled for simply the cost of materials. Many of the crops grown on what is called the market farm currently use sprinkler irrigation. Sprinkler irrigation waters all of the field at a water efficiency rating of around 40-50%. Drip irrigation only waters the desired plants at a 96-98% water efficiency. Every gallon of water pumped takes electricity, hence increasing the water efficiency and only irrigating the desired plants leads to significant water savings and reduction in energy costs. A secondary benefit is a significant reduction in weed growth and labor to weed the crops as only the plants you are cultivating are irrigated. The sprinkler irrigation of crops could be replaced by an off-grid drip irrigation system with significant environmental and financial benefit.

Fossil fuel energy production is steadily being replaced by renewable energy on the grid. The levelized cost of electricity (LCoE) of renewable energy is below that of fossil fuel energy production. We have seen an accelerating trend in early retirement of fossil fuel generation, being replaced by the cheaper option, renewable energy. It really is simple economics. There is a downside to this trend; the Duck Curve and the wind doesn't always blow. These two facts will lead to significant energy supply variation, consumer cost during peak loads and possibly, as we have seen during the wildfires in California, significant energy insecurity. As our population steadily increases, even more load will be placed on the grid. By moving in the direction of off-grid energy production, farmer can ensure they have a steady supply of power for irrigation needs and insulate themselves from the ever increasing costs of electricity.

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Unfortunately, due to both COVID-19 pandemic and customer privacy concerns, more off-grid PV irrigation systems were not located. The authors are relatively certain these systems exist in Klamath County as surely there must be more than one out of the 1,005 register farms in 2017. There has been a significant increase over the last few years in the cultivation of hemp and marijuana in seasonal greenhouses where off-grid PV drip irrigation systems are an ideal solution considering the portability of such systems, you see.

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Appendix A

PV System Component Costs

Item	Rating	Aproximate Price
Battery		
35 amp-hour	12V	$ 80.00
75-100 amp-hour	12V	$ 150.00
200 amp-hour	12V	$ 400.00
Solar Modules		
Multicrystaline	385-400W	$ 200.00
Inverters		
Small 120V	330W	$ 100.00
Medium 120V	1.5kW	$ 250.00
Medum 240V	4kW	$ 1,000.00
Large 240V	10kW	$ 2,500.00
MPPT Charge Controler		
30amp MPPT	12 or 24V	$ 120.00
40amp MPPT	12 or 24V	$ 150.00
60amp MPPT	12, 24, 48V	$ 180.00
120amp MPPT	12, 24, 48V	$ 400.00
Racking/Mounting		
UniRac 310168C > SolarMount 168 Inch Rail > Clear	1 / module	$ 55.31
UniRac 302035M > SolarMount Pro Series Universal End Clamp - Preassembled, with Rail End Cap	4 / module	$ 3.15
UniRac 302030M > SolarMount Pro Series Universal Mid Clamp - Preassembled, Integrated Bonding - 30-51mm	2 / module	$ 2.60
UniRac 307134M > SolarMount 40 Inch - 72 Inch Adjustable Tilt Leg Kit	2 / module	$ 48.50
Unirac 304001C > L-Foot Serrated, with Integrated Bonding w/ T-Bolt	4 / module	$ 2.80
Electrical		
EcoCable 10 AWG PV Cable	per ft.	$ 0.45
Baomain ANL-40A Electrical Protection ANL Fuse 40 Amp with fuse holder 1 Pack		$ 7.19
ELECFUN Tinned Copper Cable Lugs with Spy Hole Battery Cable Ring Terminal Connectors		$ 7.99
HQ Solar MC4 Branch Connectors MMF+FFM Pair (5 Pairs)		$ 39.99
ECO-WORTHY 5 Pairs MC4 Connector Male/Female Solar Panel Cable Connectors		$ 5.08
VIKOCELL Solar MC4 Inline Fuse Holder 20A Connector W/Fuse		$ 10.88

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AC and DC Pump Costs (typical)

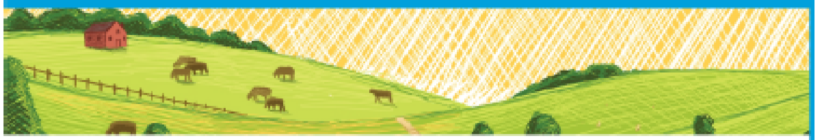
There are many differing types and designs of pumps that can be used in irrigation, an extensive list that is beyond the scope of this report. The pumps shown in the table are typical surface pumps used for irrigation. Submersible pumps and surface pumps as used in a well application are not described at this time yet are relatively similar in cost. The performance of these well pumps will vary in flow rate based on the distance the water must be lifted out of the well or feet of head.

Item	Rating	Aproximate Price
	DC	
12/24V small Drip system	3.3 gal/min open-flow, 60psi max	$ 120.00
12/24V large drip system	8 gal/min open-flow, 60psi max	$ 220.00
12/24V sprinkler	20 gal/min open-flow, 70psi max	$ 340.00
48V sprinkler, small	5-15 GPM (19-57 LPM), 25-65 PSI (1.7-1.4 Bar)	$ 940.00
48V sprinkler, large	15-35 GPM (38-132 LPM), 30-90 PSI (2-6 Bar)	$ 1,100.00
	AC	
120/240V	70 GPM 2 HP	$ 350.00
120/240V	160 GPM 5 HP	$ 900.00
480V, 3-phase	10 HP, 200 ft. Max. Head	$ 2,800.00
480V, 3-phase	25hp	$ 3,500.00

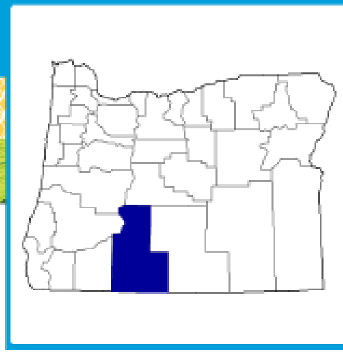
Appendix B

Klamath County Agricultural Statistics [17]

2017 CENSUS OF AGRICULTURE *County Profile*



Klamath County
Oregon



Total and Per Farm Overview, 2017 and change since 2012

	2017	% change since 2012
Number of farms	1,005	+5
Land in farms (acres)	482,999	-26
Average size of farm (acres)	481	-29
Total	**($)**	
Market value of products sold	192,598,000	+6
Government payments	2,033,000	+4
Farm-related income	7,993,000	+1
Total farm production expenses	175,848,000	+6
Net cash farm income	26,776,000	+4
Per farm average	**($)**	
Market value of products sold	191,640	+1
Government payments		
(average per farm receiving)	15,173	+59
Farm-related income	20,654	-8
Total farm production expenses	174,973	+1
Net cash farm income	26,643	-1

4 Percent of state agriculture sales

Share of Sales by Type (%)

Crops	53
Livestock, poultry, and products	47

Land in Farms by Use (%) [a]

Cropland	31
Pastureland	53
Woodland	13
Other	3

Acres irrigated: 165,541
34% of land in farms

Land Use Practices (% of farms)

No till	3
Reduced till	5
Intensive till	13
Cover crop	3

Farms by Value of Sales

	Number	Percent of Total [a]
Less than $2,500	336	33
$2,500 to $4,999	83	8
$5,000 to $9,999	90	9
$10,000 to $24,999	115	11
$25,000 to $49,999	92	9
$50,000 to $99,999	72	7
$100,000 or more	217	22

Farms by Size

	Number	Percent of Total [a]
1 to 9 acres	177	18
10 to 49 acres	244	24
50 to 179 acres	249	25
180 to 499 acres	161	16
500 to 999 acres	84	8
1,000 + acres	90	9

USDA United States Department of Agriculture
National Agricultural Statistics Service
www.nass.usda.gov/AgCensus

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