Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

Technology Sector
Agriculture

Product Category

Pumping - Automatic Self-Cleaning Disc Filters

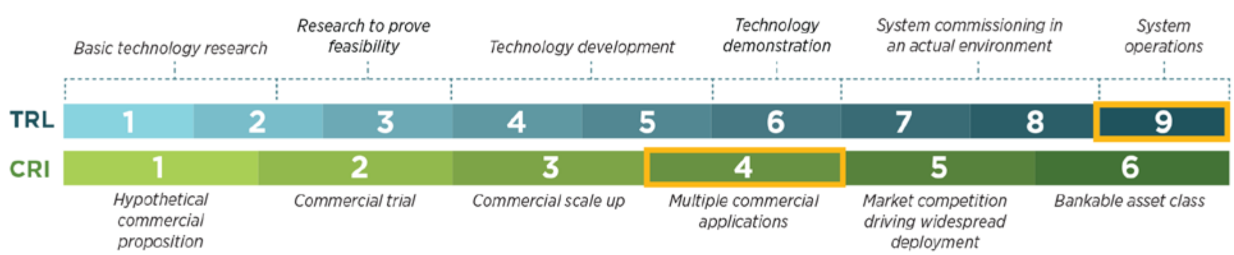
Last Updated
12/20/2018

Figure 1: Low pressure self-cleaning water filter.

Product Category Overview

Automatic self-cleaning disc water filters are used to treat irrigation water pumped from wells to prevent clogging of irrigation water delivery devices (e.g. sprinklers, drip tape). All filters result in indirect energy losses in the irrigation system due to water pressure loss across filters. Disc filters result in lower pressure head losses than other systems such as sand media filters. Self-cleaning filters use a backflush process to reverse the flow of water and clean the filter media. The water used from the backflush process is drained from the system. Self-cleaning filter systems require less maintenance and maintain optimum filtration efficiencies for long periods of time, but backflush pressures are typically higher than running pressures, leading to requirements for larger, more powerful pumps to incorporate the backflush cycles. Reducing backflush pressure requirements can therefore result in direct energy saving. Backflushing also leads to some water loss, so minimizing water use for self-cleaning improves water use efficiency.

Characterization at a Glance



Product Category Characterization

Energy Benefits

Backflushing traditional disc filters typically require 40 psi water pressure. A reduced backflush water pressure requirement of 30 psi can achieve significant energy savings.

Non-Energy Benefits

Self-cleaning filter systems require less maintenance and sustain optimum filtration efficiencies without increasing water pressure loss across the filter, in comparison to systems cleaned manually. Reducing the backflush pressure requirements allows the use of smaller, less powerful pumps.

Product Category Differentiation

High efficiency disk filters require lower water pressure for self-cleaning backflushes. They are typically modular and constructed of corrosion resistant high-density plastics, prioritizing customization, simple installation, and easy maintenance.

Installation Pathway and Dependencies

Filters are installed between the water pump and the water distribution and irrigation systems. Different water sources (groundwater, surface water) and different irrigation technologies (sprinkler, drip line) require different filtration technologies. For example, sand media filters are most efficient for filtering surface water carrying plant debris and other organic matter, but these filters typically experience the greatest head loss. In contrast, groundwater may require fine filters such as 100-140 micron size mesh disc filters that can remove the relatively small amounts of fine silts and clays. Filtration systems have to be selected and appropriately sized for the irrigation system used. Self-cleaning filter systems require less regular maintenance than manually cleaned systems.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
Netafim	LP Disc-Kleen Filter	Disc filter	Filtration through the entire depth of the disc ring; shorter backflush time; 40-800 gpm flow depending on configuration.
Netafim	Apollo Disc-Kleen Filter	Disc filter	Corrosion-proof - made from high density synthetic materials; easy maintenance; 400-3200 gpm flow depending on configuration.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review.

Location	Application	Results	Reference
Iran	Field test Automatic backflush filters compared to no-backflush disc filters and sand/disc filter combos. Water flow loss (l/s) and filtration efficiency (% contaminant removed) measured under low, moderate and high water contamination rates (<50, 50-100, >100 mg/l suspended slid+algae respectively).	Automatic backflush system averaged 23% lower water flow loss compared to the other systems at all contamination levels. Comparable filtration efficiencies for all systems were observed at low and moderate contamination rates; ~22% decrease in filtration efficiency was observed for the automatic backflush disc filters compared to the other systems under high water contamination rates.	[1]
Unknown	Lab test. Comparison of automatic backflush disk filter with 30psi pressure requirement to similar system with 40psi pressure requirement. Energy use measured.	Up to 15% decrease in energy use.	[2]

References

[1] M. Gharrari and J. Soltani, "Evaluation and comparison of performance in the disc filter with sand filters of filtration equipment in micro irrigation systems," *Modern Applied Science,* vol. 10, no. 8, pp. 264-271, 2016.

[2] Netafim, "Low pressure automatic disc filters," 15 December 2018. [Online]. Available: https://www.netafimusa.com/wp-content/uploads/2016/08/LPDISC-Low-Pressure-Disc-Kleen-Filters.pdf.

Technology Sector
Agricultural

Product Category
Pumping – Permanent Magnet Synchronous Motors

Last Updated
11/29/2018

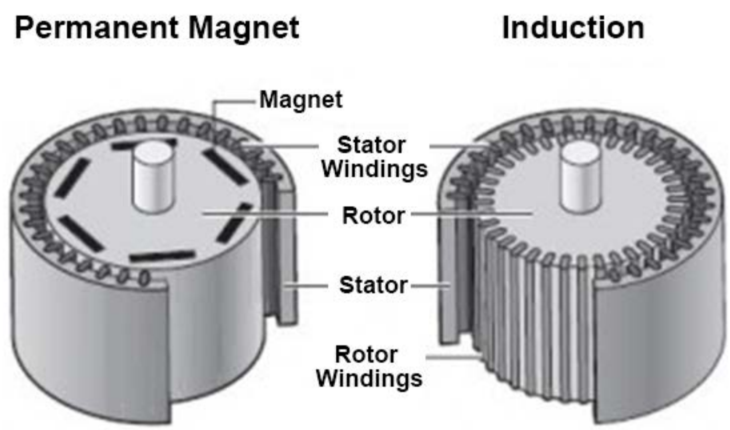
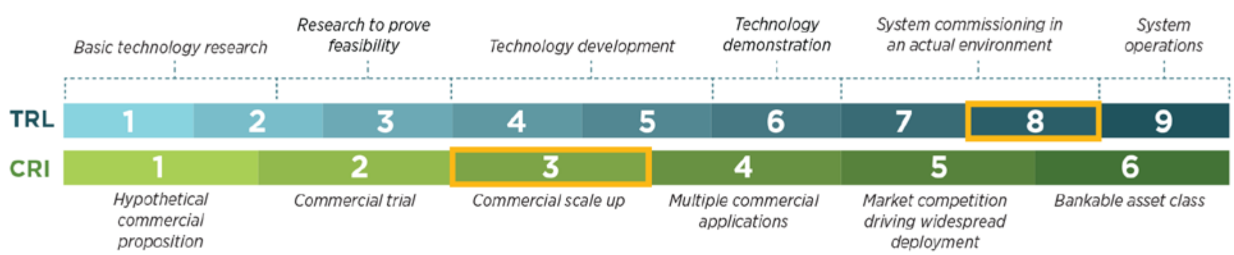


Figure 1: Permanent magnet synchronous motor (PMSM) and alternate current induction motor (ACIM) comparison.

Product Category Overview

Permanent magnet synchronous motor (PMSM) type irrigation pump motors rely on magnets to turn the rotor, which spins at the same speed as the PMSM's internal rotating magnetic field.

Characterization at a Glance



Product Category Characterization

Energy Benefits

PMSMs are rotating electrical machines that have a wound stator and permanent magnet rotors that provide sinusoidal flux distribution in the air gap, making the back electric and magnetic fields inform a sinusoidal shape. In comparison, the baseline technology—alternate current induction motors (ACIM)—has an asynchronous rotating field between the rotor and stator that results in energy loss due to slippage. Additionally the PMSM pump uses permanent magnets rather than the conventional ACIM pumps which use rotor windings. This technical alteration results in synchronous rotating fields without slippage and thus increased motor efficiency.

Non-Energy Benefits

Significantly smaller size than equivalent ACIMs, making installation and maintenance easier.

Product Category Differentiation

Most pumps and fans operating in industrial and commercial applications are currently driven by ACIM, which is an asynchronous type of motor that relies on electric current to turn the rotor. Torque is produced by electric current in the rotor. The electric current is generated through electromagnetic induction from the magnetic field of the stator windings. In an ACIM, the rotor always rotates at a lower speed than the magnetic field. A PMSM relies on magnets to turn the rotor, which spin at the same speed as the PMSM's internal rotating magnetic field. The advantages of permanent magnet motors include higher efficiencies, smaller sizes (permanent magnet motors can be as much as one third the size of ACIMs, which makes installation and maintenance much easier), and PMSMs' ability to maintain full torque at low speeds.

Installation Pathway and Dependencies

This technology is installed at groundwater wells in or near irrigated agriculture fields, typical of California's Central Valley and other water basins throughout California where access to surface water is not sufficient to meet crop irrigation needs. New installation requires the construction of a groundwater well, but obsolete pump motors are typically replaced every 10-15 years. Pump motor life is typically much shorter than the well life. Unlike ACIM motors, a variable frequency drive (VFD) is required to precisely control the speed of the PMSM to meet the application requirements for pressure, flow, volume, etc. Some new VFDs already come with permanent magnet motor control options as a standard feature, allowing operators to control the permanent magnet motor to drive the fan and/or pump more efficiently.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	**Model**	**Type**	**Differentiating Feature**
Flowserve Corporation	Pleuger PMM	Submersible pump motor	No special VFD required; standard VFDs from various manufacturers can be used.
Franklin Electric Company, Inc.	MagForce™ 6-Inch Permanent Magnet Motor System	Submersible pump motor	Sand Fighter® models are equipped with Franklin's robust Sand Fighter sealing system for durability against sand or other abrasives.
Grundfos USA	MLE pump motor	Motor only - for various pump applications	NEMA Premium IE5 efficiency rating.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review.

Location	**Application**	**Results**	**Reference**
Berlin, Germany	Field test ACIM vs VFD driven PMSM pumps in a water well field. Water flow, pressure and power demand were measured.	20-31% energy savings determined.	[1]
Hamburg, Germany	Field test Direct comparison of ACIM and PMSM pumps in a water well field. Water flow, pressure and power demand were measured.	6.8% higher global efficiency[1] compared to ACIM pumps at optimal working points. Up to 20% energy savings was determined.	[2]
USA	Lab test Comparison of identical power PMSM and ACIM submersible pumps. Water flow, power demand, power output, motor winding temperature measured.	10-14% better efficiency. Improved partial load conditions Power output (kW/hp) increased by >100% Winding temperature 10-30ºC lower	[3]

[1] Global efficiency of a pump system is the total efficiency of main components - hydraulic structure, motor, electric filter and a frequency converter; not all components are present in all pump systems.

References

[1] A. Sperlich, D. Pfeiffer, J. Burgschweiger, E. Campbell, M. Beck, R. Gnirss and M. Ernst, "Energy efficient operation of variable speed submersible pumps: simulation of a ground water well field," *Water,* vol. 10, no. 9, p. 1255, 2018.

[2] M. Beck, A. Sperlich, R. Blank, E. Meyer, R. Binz and M. Ernst, "Increasing Energy Efficiency in Water Collection Systems by Submersible PMSM Well Pumps," *Water,* vol. 10, no. 10, p. 1310, 2018.

[3] Flowserve, "Pleuger® PMM; High-Efficiency Submersible Motor With Permanent Magnet Technology for Electrical Submersible Pumps (ESP)," 2017. [Online]. Available: https://www.flowserve.com/sites/default/files/2017-08/fpd-1568-ea4.pdf. [Accessed 21 11 2018].

Technology Sector
Agriculture

Product Category
Pumping - Pump Protection Sand Separator

Last Updated
12/21/2018

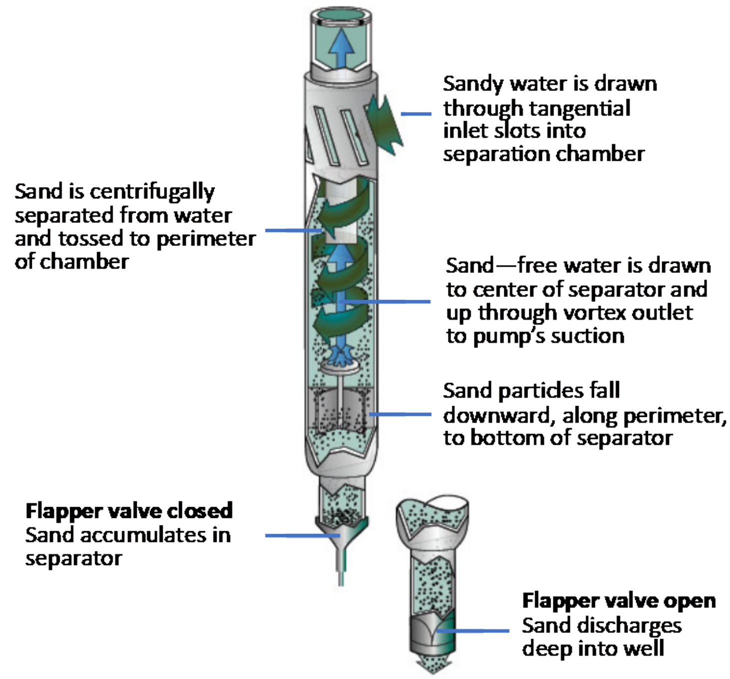
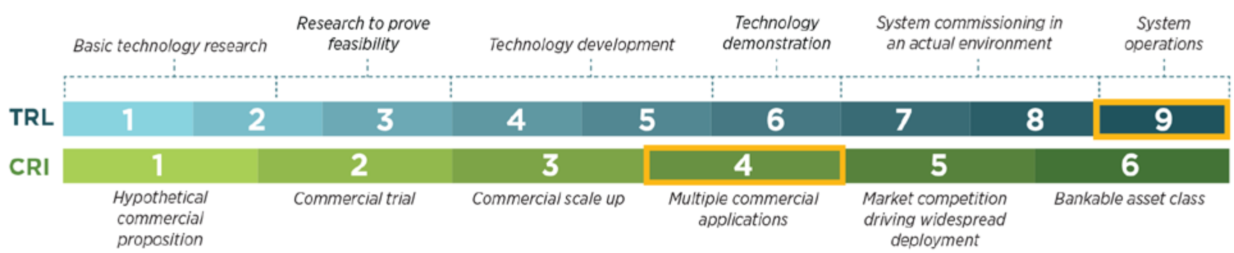


Figure 1: Pump protection sand separator (adapted from Zimmatic filtrations brochure [1].

Product Category Overview

Pump protection separators (PPS) prevent sand abrasion damage to submersible and turbine pumps in water wells, increasing their life and maintaining pump efficiency.

Characterization at a Glance



Product Category Characterization

Energy Benefits

Abrasion damage from sand and silt in groundwater damages pump impellers, leading to reduced pump efficiency and eventual pump failure and replacement. By providing a pre-filtration step that removes abrasive solids from the pump inflow, PPS can significantly reduce impeller damage and maintain pump operation at optimum efficiency.

Non-Energy Benefits

Reducing abrasion damage to pumps significantly prolongs pump life. Downstream filtration requirement is also reduced.

Product Category Differentiation

The PPS relies on particle density in a vortex flow for removal so it can filter out particles of any size. In addition, the device is self-cleaning and accumulated material is automatically removed via flapper valve at the bottom. In contrast, regular pump intake screens can filter out larger solids but not fine sand and other fine abrasive material, are subject to clogging and require more frequent cleaning and maintenance.

Installation Pathway and Dependencies

The PPS attaches to the intake of groundwater pumps, and can be installed either when pump is first deployed or as retrofit. Wells need to have sufficient depth to allow PPS installation below the pump with appropriate clearance to the bottom of the well

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
Lakos	PPS series - high-flow pump protection sand separator	Vortex flow particle separator	For applications >100 gpm
Lakos	SUB-K series - low-flow pump protection sand separator	Vortex flow particle separator	For applications <100 gpm

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review.

Location	Application	Results	Reference
Canada	Field test PPS installed on pumps compared to regular intake screened pumps Sand accumulation in well sump and pump efficiency measured.	116 liters of sand accumulated in well sump over 203 days. Pump efficiency remained in optimal range over 203 days. Previously pumps without PPS lasted for 103-143 days before replacement was required.	[2]
USA	Field test Pump life tested to the point of replacement for pumps with and without PPS.	Pumps with PPS lasted four times longer than pumps with regular intake screen under identical conditions.	[3]

References

[1] Zimmatic, "Irrigation Filtration," 2014. [Online]. Available: http://www.zimmatic.com/stuff/contentmgr/files/10/d07c27a98d33a3c5a7483f117707808c/pdf/lindsay_zimmatic_bro_filtration_1117.pdf. [Accessed 4 January 2019].

[2] M. Briffett, "Desander protects downhole pump," *Oil & Gas Journal,* 11 5 2001.

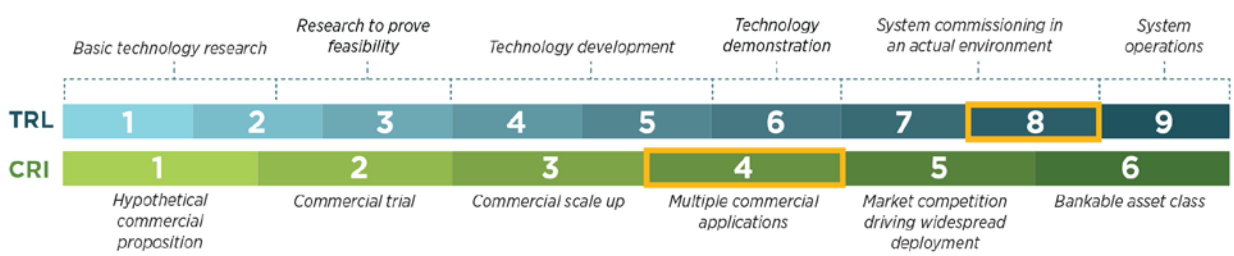
[3] Lakos, "PPS_Brochure," [Online]. Available: http://www.lakos.com/_literature_182220/LS-990_PPS_Brochure. [Accessed 21 December 2018].

Technology Sector Agriculture Product Category Irrigation - Smart Digital Dosing Pumps Last Updated 01/04/2019	 *Figure 1: Smart digital dosing pump.*

Product Category Overview

Smart digital dosing pumps supply liquid fertilizers and other chemicals to the irrigation water; efficiency is achieved by extremely high dosing precision and uniformity, and integration into a whole irrigation system monitoring and control system.

Characterization at a Glance



Product Category Characterization

Energy Benefits

Energy efficiency is achieved by extremely high dosing precision and uniformity, as well as integration into a whole irrigation system monitoring and control system. By more accurately gauging fertilizer application rates, farmers can reduce total fertilizer use and amounts of water applied during fertigation (fertilizer + irrigation) events, which in turn leads to reduced energy use.

Non-Energy Benefits

Accurate fertilizer application is essential in agriculture. Too-little fertilizer leads to reduced yields, so farmers typically err on the side of applying more than enough in order to maximize productivity. Over-application of fertilizers increases costs, and can lead to increased greenhouse gas (N_2O) production, nitrate leaching and groundwater contamination. Smart digital dosing pumps provide the most accurate fertilizer application rate regulation, thus reducing application uncertainty and allowing farmers to apply the least fertilizer necessary for their crops. This in turn reduces costs for farmers and mitigates potential environmental pollution. In addition, smart dosing pumps can typically be integrated into a whole-farm management system.

Product Category Differentiation

Conventional manually-operated dosing pumps provide fertilizer distribution into an irrigation network based on farmers' estimates of crop fertilizer requirements and system flow rates. Smart dosing pumps take the guesswork out of liquid fertilizer application by relying on measured flow rates and precise fertilizer delivery to meet exact fertillizer application targets.

Installation Pathway and Dependencies

Fertigation, that is the inline application of liquid fertilizers in irrigation water, requires the installation of small holding tanks and systems for dosing fertilizers into the irrigation water stream. These systems are typically easily accessible and interchangeable.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	**Model**	**Type**	**Differentiating Feature**
Grundfos	SMART Digital DDA	Diaphragm dosing pump	AutoFlowAdapt (automatic pump adjustment under variable flow rate), and integrated flow measurement
In-Fluid	Compact Dosing Robot	Magnetically driven dosing pump	Wi-Fi equipped, magnetically driven pump is not affected by pressure changes

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review.

Location	**Application**	**Results**	**Reference**
Germany	Lab test Standard dosing pump (Grundfos DMI 3-10) with synchronous motor and stroke length adjustment compared to Grundfos SMART Digital pump (DDA-FCM 7.5-16) Dosing accuracy and precision were measured.	1) Dosing accuracy (deviation from set point) DMI ±5.6-21% DDA-FCM ±<1% 2) Repeatability DMI ±0.1-8% DDA-FCM ±1.4% Overall, study estimates 5-19% average yearly saving in dosed chemicals with the DDA-FCM pump	[1]

References

[1] D. Rehmann and P. Rose, "Vergleichende Untersuchungen zur Dosiergenauigkeit von Präzisions-Membranpumpen (Comparative studies on the dosing accuracy of precision diaphragm pumps)," 2010. [Online]. Available: https://www.hswt.de/forschung/forschungsprojekte-alt/lebensmitteltechnologie/dosiergenauigkeit-membranpumpen.html. [Accessed 3 January 2019].

Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

Technology Sector
Agriculture

Product Category
Irrigation - Smart Meter-Based Water Use Monitoring Software

Last Updated
12/13/2018

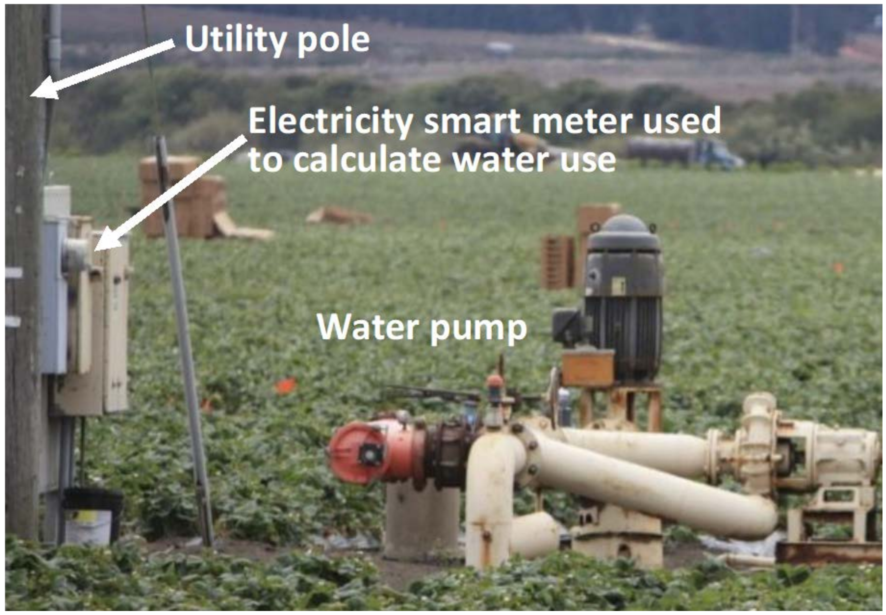
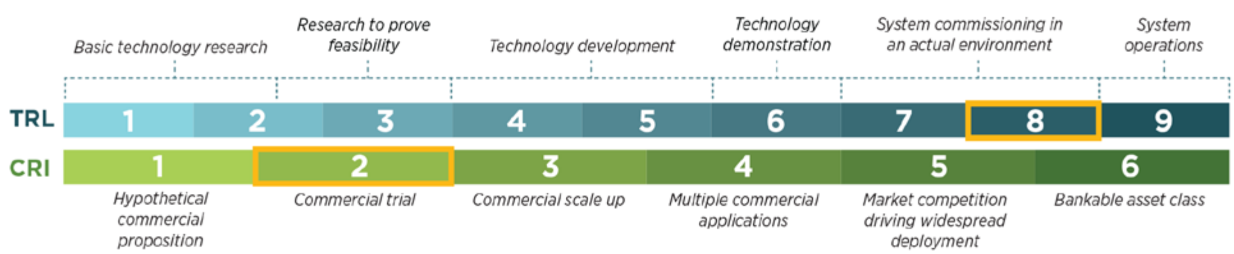


Figure 1: Smart Meter application for water use monitoring.

Product Category Overview

This product is a type of data analytics software that uses electrical use data from investor-owned utility Smart Meters to calculate water extraction and application volumes for irrigation well pumps and booster pumps.

Characterization at a Glance



Product Category Characterization

Energy Benefits

Software technology that uses Smart Meters to monitor water use provides reliable measurements essential for efficient water use on a farm. These measurements provide direct, real-time feedback to the farmer who can use the information to ensure that crops are not overwatered (reducing pumping and saving energy) and that pumps operate during off-peak periods (saving money and aligning with renewable electricity availability).

Non-Energy Benefits

The technology improves water use efficiency by providing data to optimize watering rates. It can also save significant amounts of water by providing rapid leak detection.

Product Category Differentiation

Typically volumes of water pumped are either not measured at all or estimated using mechanical or electronic flow meters that have to be installed in existing infrastructure and regularly calibrated. Accurate flow meters are expensive. In contrast, this technology uses Smart Meters to measure electricity use and provide reliable estimates of volume of water pumped. Installation of additional devices is not necessary, and network infrastructure used to deliver measurements to the service provider and end user is already in place.

Installation Pathway and Dependencies

This technology relies on existing infrastructure—electric motor operated pumping stations and existing electric utility Smart Meters—so typically no new installation is necessary. It requires point of service calibration to ensure reliable conversion of electricity use to pumped water estimates. If Smart Meters aren't already available they must be installed.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
PowWow Energy	Pump monitor	Service software converting electrical utility Smart Meter data into water-pumped equivalents.	Currently only known vendor for this type of technology.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 1.

Table 2: Summary of results from literature review

Location	Application	Results	Reference
California, USA	Field test at 5 sites. Technology compared to farmer estimates for water application and validated with flow meters. Energy used for pumping and water flow-rate measured. Volume of water applied calculated from flow-rate measurements	Water use efficiency (tons/acre-feet) improved by 9%. Energy use efficiency (tons of water/MWh) improved by 13%.	[1]

References

[1] O. Jerphagnon. "Data mining platform to address water-energy nexus in Agriculture." Emerging Technologies Coordinating Council. [Online]. Available: https://www.etcc-ca.com/sites/default/files/summit2018spring/olivier_jerphagnon_-_final.pdf. [Accessed Dec. 4, 2018].

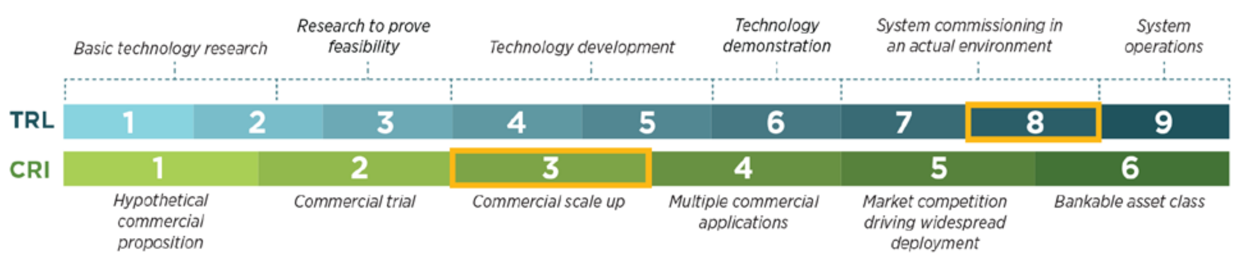
Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

Technology Sector Agricultural Product Category Pumping – Variable Frequency Drive System Last Updated 11/29/2018	 Figure 1: Variable frequency drive running a groundwater pump.

Product Category Overview

Variable frequency drives (VFDs) are adjustable-speed drives to control alternating current motor speed and torque by varying motor input frequency and voltage. There are three basic designs for VFD alternating current motor controls: Six Step Inverter (variable voltage source), Current Source Inverter, and Pulse Width Modulated Inverter (PWM; constant voltage source). Each type possesses unique electrical characteristics to consider in the application for load requirements, motor selection, system operating efficiency, and power factor. PWM is the most prevalent. Energy savings are achieved by modulating the motor speed at varying capacity demands.

Characterization at a Glance



Product Category Characterization

Energy Benefits

VFD saves energy by modulating the pump engine motor speed at varying capacity demands. This ensures that VFD-driven pumps operate at close to maximum efficiency under a much wider range of operating conditions than single speed pumps.

Non-Energy Benefits

By regulating the pumping rate, farmers can more accurately target the water demands of different fields/crops and thus reduce water use. Frequency converters increase pump motor life by protecting motors as well as allowing a soft start and stop for submersible motors. In addition, irrigation systems supplied by a VFD-driven pump are much more flexible, separating cropping decisions from irrigation system limitations, which allows farmers to better tailor their operations to market demands and crop rotation decisions by, for example, planting different crops in fields supplied with the same irrigation system.

Product Category Differentiation

Single speed pump engines are designed to operate at maximum efficiency in a narrow range of operating conditions defined by each pump's respective power curve. VFDs are electronic systems that convert alternating current (AC) to direct current (DC) and then simulate AC with a changed frequency, thereby changing the speed of the motor. Decreasing motor speed results in decreased energy use. Influent, bypass, or effluent pressure valves are alternative technologies used to regulate system pressure and/or flow rate, but these technologies do not decrease the pumping station's energy consumption and put additional pressure on the pumping system, resulting in decreased equipment lifespan.

Installation Pathway and Dependencies

VFDs are installed as an external system adjacent to the pump. They can be retrofitted onto existing pumping systems and ideally integrated with system controls and sensor networks (such as water flow or pressure sensors). Power quality is an important consideration when installing VFDs because they are sensitive to transient voltages, due to either the servicing utility or the switching of other loads on the same supply line. Additionally, harmonic currents caused by the VFD can cause increased heating in electric motors, and reduced flow rates can cause increased heating in water-cooled engines and pumps.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
Valley Water Management	Yaskawa iQPump® 1000 VFD	pump speed modulating driver	Drive Connect™ - pressure sensors control VFD from the end of the center pivot irrigation system.
Lindsay	Zimmantic®	pump speed modulating driver	FieldNET remote irrigation management for continuous monitoring and control.
Gould	Aquavar SPD	pump speed modulating driver	Dual Set Point: The S-Drive has the capability to be programmed with two pressure set points.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review

Location	**Application**	**Results**	**Reference**
California, USA	Field test VFDs compared to conventional throttled single speed pumps in five pumping stations serving different irrigation networks. Discharge pressure, pump rpm, and horsepower used were measured.	32-56% reduction in energy used.	[1]
Nebraska, USA	Lab simulation GIS- assisted simulation on 100 randomly selected pivots located in 10 Nebraska counties using high resolution Digital Elevation Model (DEM) datasets; center pivot irrigation systems.	Based on expected energy use, cost savings were calculated at $0.25-$3.00/hour/center pivot system, depending on pivot system configuration.	[2]
Turkey	Lab test VFDs compared to conventional single speed pump throttled by three different valve types (inlet, outlet, and bypass). Power consumption, water pressure, and flow rate were measured.	No power savings with VFD were recorded at pump capacity (maximum) flow. 11-87% energy savings were measured depending on valve type and flow rate.	[3]

References

[1] B. Hanson, C. Weigand and C. Orloff, "Variable-frequency drives for electric irrigation pumping plants save energy," *California Agriculture,* vol. 50, pp. 36-39, 1996.

[2] D. Brar, "Conservation of energy using variable frequency drive for center pivot irrigation systems in Nebraska, Masters Thesis," University of Nebraska, Lincoln, 2015.

[3] A. Arslan and A. Sahib, "Comparison of Energy Efficiencies of a Small Centrifugal Pump at Constant and Variable Speed Operations," *Journal of Agricultural Sciences,* vol. 22, pp. 444-454, 2015.

Technology Sector
Agriculture

Product Category
Irrigation - Wireless Sensor Networks

Last Updated
11/29/2018

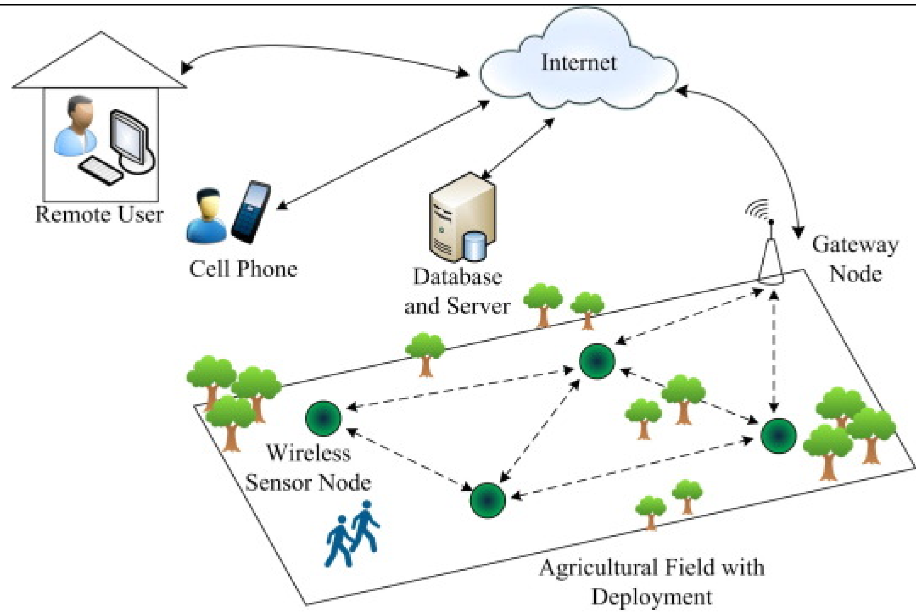
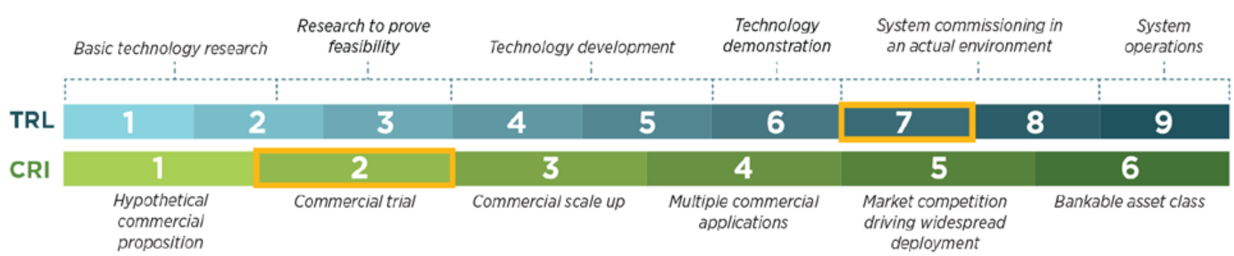


Figure 1: Wireless sensor network for precision agriculture.

Product Category Overview

Wireless precision agriculture sensor networks (WSN) integrate real-time, on-farm monitoring sensors into a comprehensive data gathering system that allows empirical farm management. To cope with farming under limited water availability, wireless sensors, actuators, and their networks present themselves as important tools for the collection and presentation of acquired data to enable a precise, rational-decision based system of agricultural irrigation.

Characterization at a Glance



Product Category Characterization

Energy Benefits

WSN take the guesswork out of irrigation water application by providing direct feedback through a network of soil (e.g. soil moisutre, electrical conductivity), climate (e.g. temperature, humidity, evapo-transpiration), and irrigation system (e.g. flow rate, water pressure) sensors. These feedback mechanisms allow the farmer to more precisely target water delivery to each crop, field, or field section, thus maximizing yield potential while minimizing water wasted due to over-watering. Optimizing water use directly saves energy by reducing pumping duration or intensity. Remote scheduling of irrigation can shift energy use to lower cost off-peak energy periods. System energy savings are increased by using low energy sensor and communication solutions (e.g. ZigBee, LoRa) rather than more energy-intensive solutions such as Wi-Fi.

Non-Energy Benefits

Crops require a precise irrigation schedule. Both under- and over-watering have negative effects. Under-watering can lead to reduced yields and plant stress leading to reduced resistance to pests and disease. Over-watering can lead to nutrient leaching and and increases in root rot diseases, which can result in yield reductions. More precise irrigation results in higher yields and optimum water use.

Product Category Differentiation

Currently most irrigation systems are controlled via manually operated valves, and farmers have to go to the field to check relevant indicators such as soil moisture and crop appearance (looking for signs of vilting etc). Particularly in large farm operations this can translate into significant costs in both fuel and man-hours. WSN can significantly reduce these costs while improving water use efficiency on the farm.

Technology Readiness Assessment and Projection

- Current Technology Readiness Level assessment:
  While all components of WSN are available, only pilot studies of such networks appear to have been described to date. There is currently no commercial provider of integrated WSN.
- Short-term TRL projection:
  There is recognized need for WSN implementation in precision agriculture. It is highly likely that commercial providers will start providing WSN services in the very near future.

Installation Pathway and Dependencies

WSN’s installation and implementation will require both significant upfront costs as well as a potentially steep learning curve for farmers switching from traditional irrigation methods to sensor network-based irrigation systems. The network systems will need to be rugged and robust enough to minimize field failure, with sufficient back up in place to quickly alert farmers to problems that require a worker’s attention. The components of the networks are available, though integrating them into a farm-specific system will involve a step up in complexity.

Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
Zigbee Alliance	ZigBee	Communications technology	Long range, low cost, low power consumption.
Crossbow Technology	MICA2	Sensor node	Off-the-shelf hardware; does not require use of predefined protocols.
Intel Research	Imote2	Sensor node	Built around the low power PXA271 XScale CPU; integrates an 802.15.4 compliant radio.
Met One Instruments	Met station one (MSO)	Weather station	Digital sensor, provides RS-232/485, and SDI-12 output signals.
Stevens	Hydra probe II soil sensor	Sensor	Accurate, rugged and dependable.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review

Location	Application	Results	Reference
Montana, USA	Field test Design and instrumentation of variable rate irrigation, a wireless sensor network, and software for real-time in-field sensing and control of a site-specific precision linear-move irrigation system. Probes measured soil moisture and soil temperature; an in-field weather station monitored air temperature, relative humidity, precipitation, wind speed, wind direction, and solar radiation.	Demonstration of functionality, energy or water savings not reported.	[1]
Malaysia	Greenhouse test A test was conducted to compare the efficiency of irrigation using two methodologies: schedule and automated. Soil moisture and water use were measured.	Average savings of 1,500 ml water per day per tree were determined.	[2]
Spain	Field test Comparison of scheduled irrigation and sensor network irrigation. Soil moisture, water applied measured.	72% less water used with sensor network irrigation (17.2 vs 62.1 L/irrigation event).	[3]

References

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[3] N. Sales, "Cloud-based Wireless Sensor and Actuator System for Smart Irrigation," Instituto Superior T́ecnico, Lisbon, Portugal.