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Learning Note
September 2022

TECHNOLOGICAL INNOVATIONS

FOR RURAL WATER SUPPLY IN LOW-RESOURCE SETTINGS

Rural Evidence and Learning for Water (REAL-Water) is a initiative from the United States Agency for International Development (USAID) and supports policy makers, development partners, and service providers to make strategic decisions and implement best practices for water management through implementation research.

CHALLENGE

Globally, the Sustainable Development Goals (2015–2030) are driving efforts to increase water service levels, while ensuring that services are affordable and no vulnerable population is left behind (United Nations 2018). In concert with global development goals, the United States Agency for International Development (USAID) Rural Evidence and Learning for Water (REAL-Water; 2021–2026) program focuses on identifying ways to expand water access and safety in rural areas of low- and middle-income countries. Rural areas pose special challenges for water supply, as homes may be too few or too dispersed to justify the cost of installing underground pipes from a high-quality water supply source or a centralized drinking water treatment facility. **As of 2020, the majority of people lacking even basic water services (i.e., water from a protected source requiring no more than 30 minutes to collect) lived in rural areas** (WHO UNICEF Joint Monitoring Programme (JMP) 2021).

OBJECTIVES

This note provides an overview of water supply technologies that are innovative in either design or application (i.e., not yet commonplace)

and promising (i.e., show potential for advantages exceeding the status quo) in rural areas such as small villages and dispersed settlements. It highlights categories of high-technology concepts (i.e., advanced electronic devices, materials, and designs) that offer a greater range of options to decision-makers, donors, practitioners, and consumers who manage rural water supplies. The concepts may have sufficient merit to warrant further exploration and testing within later stages of REAL-Water or other implementation research programs; however, the REAL-Water consortium does not endorse or relatively rank specific providers of these technologies. Specific technology choices should be weighed relative to one's local setting and context. Information is summarized to evaluate conditions and trends in rural water innovation, leading to overarching recommendations.

TECHNOLOGY SYNOPSES

1. SOLAR PUMPS

CATEGORY

Extraction/Collection

STATUS

Commercially available

Rural communities in Africa, Southeast Asia, and parts of Latin America and the Caribbean may not be connected to an electrical grid; however, most of these locations receive abundant solar irradiation.

SOLAR-POWERED WATER SUPPLY SOLUTIONS OFFER VAST (AND UNDERAPPRECIATED) POTENTIAL FOR REPLACING GRID ELECTRICITY OR DIESEL GENERATORS.

Advantages include energy independence, sufficient water quantity, fewer queues, minimal maintenance, and the ability to raise water into elevated tanks to support gravity-fed distribution. Thus, solar pumps provide off-grid communities with a fairly reliable and climate-friendly means of producing high-quality water with few interruptions (e.g., extended cloudy periods, vandalism or theft). Adequate technical capacity to operate and maintain these systems is critical. Financing upfront, maintenance, and eventual replacement costs can be justified by long-term cost-effectiveness relative to alternatives. Solar pumps are **commercially available** and used for rural water supply applications on several continents.

Community-scale solar-powered water pumping system in Tanzania (Source: Water Mission)

2. COMMUNITY-SCALE DISINFECTION

WATER DISINFECTION REPRESENTS A LOW-COST, EFFECTIVE MEANS OF INACTIVATING DISEASE-CAUSING MICROORGANISMS, WITH SUBSTANTIAL PUBLIC HEALTH RETURNS.

Among disinfection methods, chlorination has been implemented at points of water storage and collection (e.g., tanks, standpipes, handpumps) in small rural systems across many different geographies. Drawbacks include that chlorine is not effective against resistant pathogens (e.g., protozoan cysts), disinfection does not address chemical contamination, and higher-turbidity (cloudier) source water requires pretreatment. Research finds that centralizing water disinfection at the community scale reduces the labor burden on individual consumers. Other dosing, acceptability, and recontamination challenges might be best addressed through automated technologies. Onsite production of disinfectants such as sodium hypochlorite and ozone has undergone extensive technological development over the past decade, enhancing performance and convenience. Solar energy can power these approaches, along with UV light disinfection systems that leave no chemical residues. Newer disinfection technologies perform well in ideal settings, but they remain **under testing** to properly address challenges posed by real-world rural, low-income contexts.

CATEGORY

Treatment

STATUS

Traditional

Commercially available

Advanced

Under pilot evaluation

MSR SE200 community chlorine maker (Source: PATH)

3. MEMBRANE FILTRATION

CATEGORY

Treatment

STATUS

Traditional

Commercially available

Advanced

Under pilot evaluation

Physically separating impurities from water via membrane filtration is among the most active areas of water treatment research and development.

MEMBRANES HAVE PORE DIAMETERS OPTIMIZED TO CONSISTENTLY CAPTURE DIFFERENT CONTAMINANT SIZES ACROSS SEVERAL ORDERS OF MAGNITUDE, RANGING FROM LARGE, VISIBLE SUSPENDED PARTICLES TO TINY SALTS, METAL IONS, AND VIRUSES.

Depending on initial water quality, water may require pretreatment to prevent fouling (from microorganisms) and scaling (from hard water deposits) of the costly membranes. Energy is sometimes needed to create a pressure gradient, and regular backwashing generates a wastewater concentrate for disposal. Widely employed in high-income contexts for some time, membrane filtration is **finding new commercial applications** in low- and middle-income contexts, whether in single-step or multi-stage decentralized community water treatment systems.

4. REVERSE OSMOSIS

CATEGORY

Treatment

STATUS

Commercially available

Water scarcity and natural or human-driven water contamination affect many geographies around the world. The type of membrane filtration (Innovation 3) capable of separating the smallest contaminant sizes is termed "reverse osmosis," wherein water is pressure-forced through a membrane with very small pores. This achieves near-complete removal of all categories of contaminants, but it normally requires some pretreatment steps and incurs higher energy costs.

REVERSE OSMOSIS REPRESENTS ONE OF THE MOST EFFECTIVE FORMS OF WATER TREATMENT (EVEN FOR PURIFYING SEAWATER AND RECYCLED WASTEWATER);

however, the membranes remain relatively pricy and the process produces large volumes of concentrated "reject" water, up to 80% of the inflow. In areas where salinity or dissolved metals pose the dominant water quality challenge, reverse osmosis is becoming an **increasingly efficient treatment solution**, as technological advances and greater market penetration bring down costs.

5. SMART METERS

CATEGORY

Storage/Distribution

STATUS

Commercially available

Information and communication technology advances have enabled widespread upgrading of electronic devices in recent decades, including community and household water meters.

"SMART" METERS (WITH AUTOMATED SELF-MONITORING AND REMOTE COMMUNICATION) OFFER A WIDE RANGE OF POTENTIAL BENEFITS TO BOTH WATER SUPPLIERS AND CONSUMERS, AIDING COST RECOVERY, WATER CONSERVATION, AND SERVICE DELIVERY.

These increase accountability by efficiently tracking and transmitting water usage data throughout service areas, wherein telecommunication networks, energy supplies, and equipment must be maintained. Device availability is expanding, and replacing or retrofitting meters has become more affordable. The transition to smart meters has occurred primarily in wealthier countries, with **some entry points** into rural areas of low-to-middle income countries.

6. DIGITAL PAYMENTS

CATEGORY

Storage/Distribution

TYPE

Commercially available

Traditional cash payments for water are cumbersome to convey and susceptible to poor accountability.

DIGITAL PAYMENTS REPRESENT A RAPIDLY EVOLVING INNOVATION WITH IMPLICATIONS FOR BOTH THE FINANCIAL AND OPERATIONAL SUSTAINABILITY OF WATER SERVICE PROVIDERS.

Digital payments reduce operational costs associated with deploying or stationing employees at the point of sale. They facilitate reductions in burdensome queueing and create more flexible work opportunities. Technologies may be set up for prepayment or post-payment, and can occur via existing mobile money (electronic wallet), digital banking transactions, or self-service payment kiosks. Importantly, these systems should be tailored to offer flexible payment options or subsidies for vulnerable populations. Rural consumers may assume understanding of water supply as a paid service, although acceptability varies. While the technology is **readily available** and growing quickly in urban settings, digital payment for water use in rural areas remains less widespread.

7. DECENTRALIZED WATER QUALITY TESTING

To verify drinking water safety, water quality testing is commonly performed for urban water systems throughout the world, either in the field (in situ with sensors or onsite with portable equipment) or in a laboratory (samples collected and transported offsite for analysis). Standard field tests are available for a suite of physicochemical parameters, such as temperature, pH, electrical conductivity (to determine salinity), turbidity (suspended particulate matter), and chlorine. Measuring microbiological parameters generally requires laboratory equipment for incubation or DNA amplification, although

SEVERAL FIELD KITS FOR INDICATOR BACTERIA (A PROXY FOR PATHOGEN PRESENCE) HAVE BEEN DEVELOPED AND TESTED FOR DRINKING WATER MONITORING.

Remote and field-based monitoring approaches with low costs and high replicability **need to be disseminated more consistently** to rural, low-resource areas, and will require shifts in public accountability, technological and managerial design, incentivization, and local capacity building.

CATEGORY

Monitoring/Management

STATUS

Traditional

Commercially available

Advanced

Limited production

Under pilot evaluation

Conceptual

A satellite-enabled Virridy remote handpump sensor, mounted in green casing (Source: Virridy)

A staff member testing a water sample in Asutifi North District, Ghana. Source: Aquaya

8. SENSORS

CATEGORY

Monitoring/Management

STATUS

Limited production

Water supply infrastructure in low-resource settings has historically been plagued by a lack of ongoing oversight and maintenance.

SENSORS FOR MONITORING PIPED WATER SYSTEM PERFORMANCE (E.G., FUNCTIONALITY, FLOW RATE, BASIC WATER QUALITY) ARE WIDELY DEPLOYED BY URBAN UTILITIES IN HIGH-INCOME COUNTRIES, MANY OF WHICH REMOTELY TRANSMIT DATA TO A CENTRAL MANAGEMENT DASHBOARD.

Critically, monitoring systems must incentivize and enable responsible institutions to act upon the data produced by cost-effective sensor networks. Candidate devices and systems designed or customized for rural water settings would benefit from larger-scale markets to continue reducing costs and refining stability and reliability. **Piloting and scale-up are underway** in many countries, often involving iterative technology development.

9. DIGITAL MANAGEMENT APPLICATIONS

CATEGORY

Monitoring/Management

STATUS

Commercially available

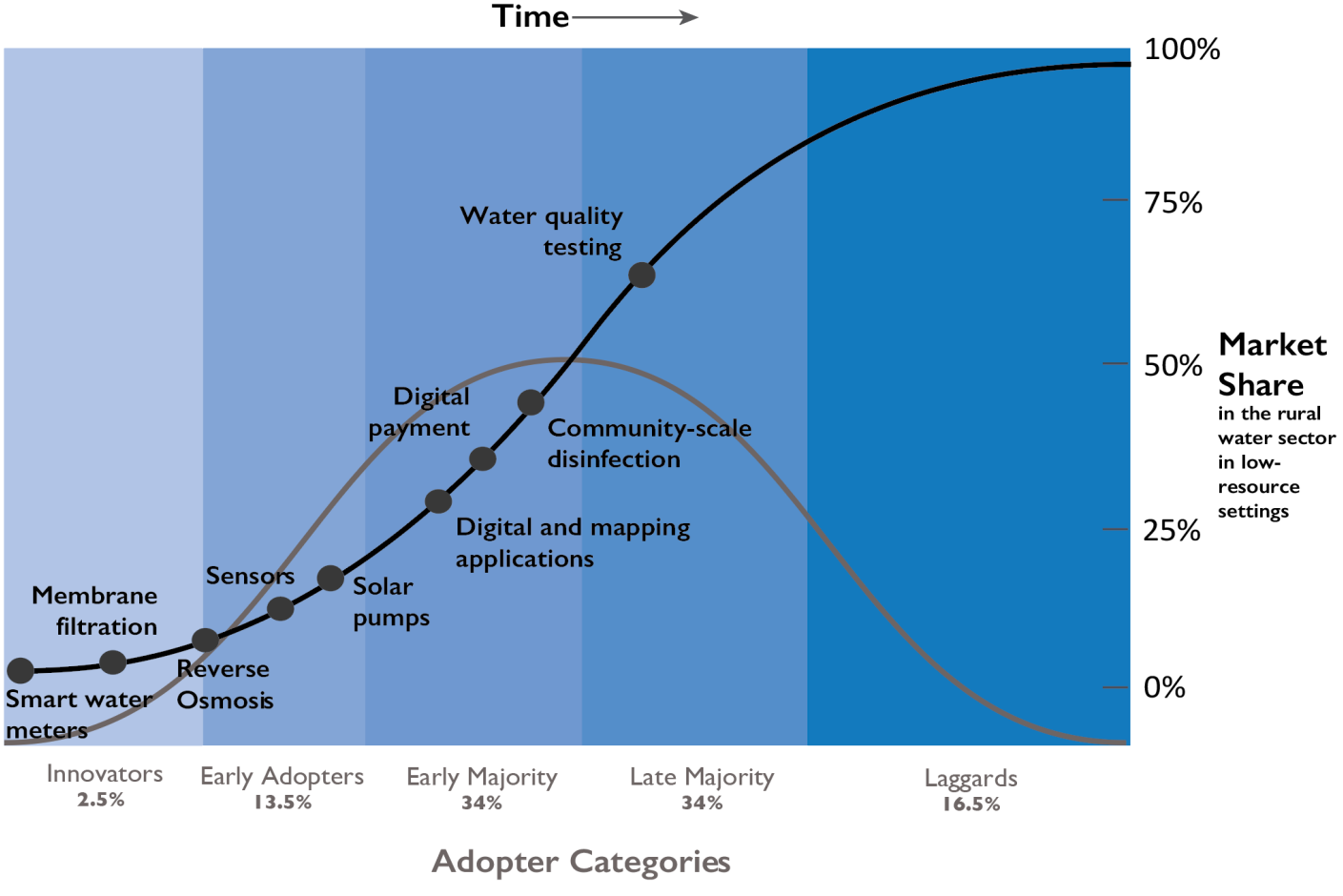
Compared to urban water utilities, rural water supplies often lack sufficient personnel, monitoring schemes, and record-keeping systems. This leads to challenges addressing routine issues, allocating resources for system management, understanding spatial and temporal resolution of data (e.g., to enable alerts), and preparing for long-term risks.

THREE PRIMARY TECHNOLOGIES HAVE POTENTIAL TO EASE DATA COLLECTION, MONITORING, AND MANAGEMENT ACTIVITIES.

First, cloud-based "supervisory control and data acquisition" software systems allow two-way remote water supply system monitoring and management. Second, "Internet of Things" systems consist of physical objects (e.g., sensors) that connect and exchange data with other devices and systems over communications networks. Third, "digital twins" offer virtual replicas of the physical water supply system with real-time updates. These automated tools reduce labor and time collecting and processing data, even facilitating machine learning and prediction. Still, they come with many common drawbacks of non-human intelligence: upfront investment, increased energy use, possible data loss or malfunction, and potential ethics concerns. Digital management applications are steeply on the rise among high-income, urban water suppliers, with fewer specialized products **under development** for remote, rural, and low-resource settings.

UPTAKE CONSIDERATIONS

Diffusion of Innovation theory explains that most people look to their social peers before adopting new ideas, and therefore spread circulates outward into larger social circles until reaching critical mass (Rogers 2003). **Later technology acceptance theories acknowledge the influence of multiple dimensions (e.g., context, psychosocial factors, and the technology itself) affecting innovation uptake decisions on multiple levels** (e.g., larger governance structure, community, household, and individual; Dreibelbis et al. 2013). Implementation science offers a pathway from passive "diffusion" to more active "dissemination," by identifying barriers to scale-up of evidence-informed practices and matching them to strategies likely to bring about performance improvement (Haque and Freeman 2021; Setty et al. 2019). Example factors supporting innovation uptake include regulatory oversight, active coalitions, cost-recovery accounting, and performance monitoring (Rouillard et al. 2016; Machado et al. 2019; Smits and Lockwood 2015).

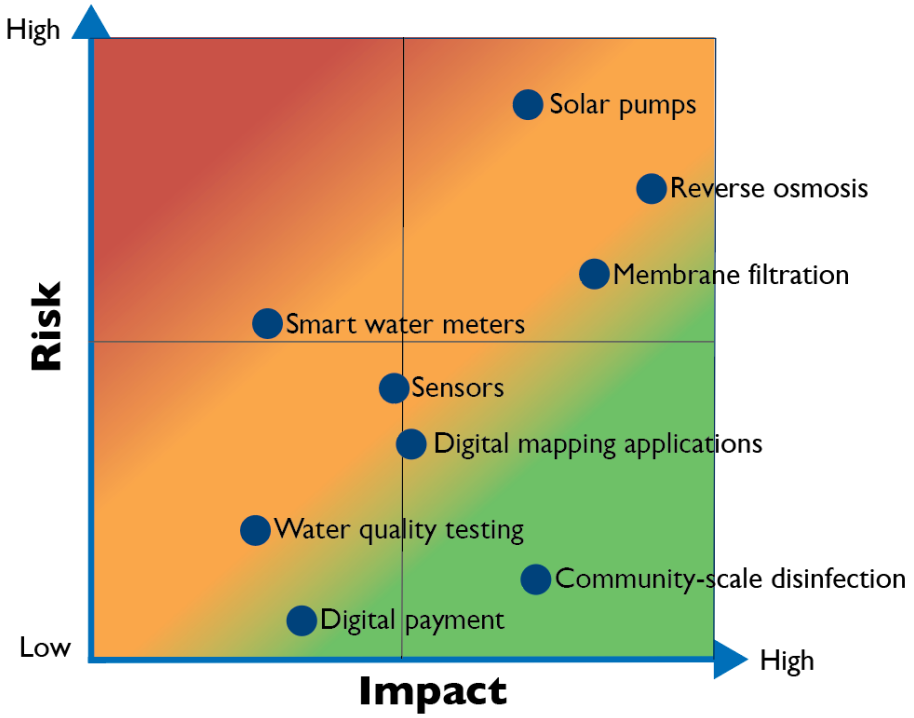


Approximate relative positions of each technology on a diffusion of innovation curve (adapted from Rogers 2003), as applicable to the "market share," in this case the estimated portion of water supplies in rural areas of low- and middle-income countries that stand to benefit (Source: The Aquaya Institute). Notes: This diagram is generalized to a global scale; results differ by geography. In addition, full market saturation is not necessarily a goal for all technologies, as the optimal suite of water supply solutions will depend on local context.

The risks and potential impacts of various technologies differ among rural settings. Since incentives for technological innovation differ in a global development context, where access to safe water represents a human right, **both the public and private sectors play critical roles in scale-up** (Wehn and Montalvo 2018). Commercialization efforts must include underrepresented parties, such as minority voices and local consumers. The rapid evolution of information and communications technology introduces further complexity into commercialization processes, but in most cases facilitates expediency and cooperation. Technological commercialization has also shifted (in large part due to consumer demand and recognition of past failures) to require a concerted emphasis on social and environmental responsibility. These foci are critical to tackling key issues, such as climate change.

RECOMMENDATIONS

All innovation categories described herein hold promise for advancing rural water supply efforts in low-resource settings. At the same time, technological innovation benefits from continued research and development, marketing, and supplier competition to address drawbacks and awaken new possibilities. Low-risk, high-impact innovations such as community-scale disinfection can be promoted in many settings, while other innovations such as reverse osmosis may render benefits under certain conditions. **Critically, partnerships coupling implementation efforts with research efforts can help to clarify the most favorable conditions for each technology.**



Approximate grid positions of each rural water supply technology category, depending on its generalized risk (e.g., financial, technological, physical) and impact (i.e., water service improvements for low-resource rural settings) (Source: The Aquaya Institute). Notes: Placement of each innovation topic is subjective and aggregated at a global level. The REAL-Water program welcomes ongoing input as to missing or differing future priorities.

The financial, technical, and social aspects of rural water supply interact in complex ways, and different bottlenecks may apply to different scenarios over time (Walters and Javernick-Will 2015; Carter 2019; REACH 2017). To better facilitate technological innovation serving rural water consumers in low- and middle-income countries, this report reached the following overarching **recommendations:**

- **Water supply managers** should incrementally adopt more advanced technologies, where justified by projected long-term cost-savings, improved verification of safe water delivery, and/or reduction of negative externalities.

- **Public sector investors** play a key role in developing business models and demonstrating the viability of serving peri-urban, rural, and remote areas. Water service implementers should set affordable price points from the outset to encourage consumer buy-in and ownership. (Learn more in the companion report: Financial Innovations for Rural Water Supply in Low-Resource Settings.)

- **Researchers and technology suppliers** should adopt user-centered, community-involved, and ecologically minded approaches (emphasizing care, interconnectedness, and integrity) to designing and testing next-generation technologies.

- **Technology suppliers** should couple new water supply infrastructure with "smart" (preferably automated or semi-automated) monitoring feedback to increase long-term accountability among technology purveyors, such as donors, governments, and service providers.

- **All parties**, in the face of climate change, should combine energy-consuming rural water supply technologies with sustainable, renewable energy sources where possible.

- **Donors, implementers, and researchers** should pair technology trials with social ("soft") science approaches, such as improvement cycles or implementation support follow-up, to periodically consider remaining barriers to change and address them with evidence-informed strategies.

- **Donors, researchers, and water supply managers** should holistically assess and prioritize risks threatening the resilience of existing rural water infrastructure.

TABLE 5. OVERVIEW OF TECHNOLOGICAL INNOVATION PROS AND CONS

Innovations	✓	✗
Solar Pumps	• Enable mechanized water pumping, treatment, and storage in areas with unreliable electricity access and expensive fuel supplies • Reduce carbon emissions and other environmental impacts, such as air pollution, associated with mechanized water systems • Reduce water supply vulnerabilities during natural disasters that affect electrical grids and fuel supply chains	• Complex engineering and technical requirements for solar pump installation and maintenance • Reduced performance during overcast and rainy conditions • High installation costs that can reduce the affordability of water services • Risk of theft
Community-scale disinfection	• Effective at treating many types of microbial contamination • Relatively low cost • May provide residual protection for stored water	• Taste and odor of treated water is objectionable in some settings • Disinfection is less effective in highly turbid waters • Quality and consistency of commercially available chlorine consumables vary • Works better when coupled with safe household transport and storage
Membrane filtration	• No or minimal energy requirements • Relatively few operational and maintenance requirements for microfiltration and ultrafiltration systems • Small physical footprints • Effective for removing a broad range of contaminants	• High procurement costs • Tendencies to foul under certain water quality conditions • Regular backwashing is needed to maintain membranes • Higher maintenance costs, training, and electrical supplies for more advanced nanofiltration systems

Reverse osmosis	• Effectively treats hard-to-remove contaminants • Rapid advances are improving technical efficiencies, lowering costs, and reducing energy requirements	• High energy requirements • Requires high technical capacities to operate and maintain systems • "Rejected" water requires careful disposal to minimize environmental contamination
Smart water meters	• Accurate, real-time data on water consumption for suppliers and consumers • Support efficient billing systems • Facilitate detection of water losses (e.g., leaks and pipe breaks)	• Reliance on telecommunication systems that are prone to disruptions in low-resource settings • Best suited for piped water supplies
Digital payments	• Greater convenience for both consumers and water suppliers • Lower fee collection costs for suppliers • Options for prepayment	• High upfront costs • Consumers require training to use connected devices • Low-income assistance programs must be available
Decentralized water quality testing	• Increasing availability of low-cost and simple technologies for both field-based and laboratory testing of water supplies • Better data for informing management priorities and apprising consumers about water quality	• Cybersecurity risks • Data collection has to be linked to effective systems for evaluating and responding to water quality information • Ongoing testing costs may exceed available operational budgets
Sensors	• Real-time functionality data for both piped and community water point sources • Enable asset monitoring and accountability post-installation	• High costs and technically challenging to implement at scale • Requires reliable energy supplies • Requires water system personnel with capacity to maintain system, and monitor and respond to data

Digital management applications	• Ability to link sensors directly to automated controls (e.g., alarms, pumps, chemical dosers) • Improved data for management (e.g., demand estimates, non-revenue water reduction) • Increased operational efficiencies	• High upfront financial investments • Requires reliable energy supplies • Requires water system personnel with capacities for monitoring and responding to electronic data and alarms

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Read the full report here.