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AMI Gold Standards Report

An Assessment of the Smart Electric Metering Landscape

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Section 1
EXECUTIVE SUMMARY

1.1 Introduction

Smart meters could be labeled as the original smart grid device. More than a decade after the earliest models of communicating electric meters were deployed, utilities are adapting to new technologies and exploring new and innovative ways of using smart meters to create additional value. While first wave use cases tend to focus on meter-to-cash considerations and basic analytics applications, there are an increasing number of use cases around grid management, customer experience, asset management, and more. There has also been an evolution at the project management level, including enhanced public outreach and communications, human capital improvements, and optimization of resource allocation. As the market landscape continues evolving through a mix of new actors, capabilities, and deployment models, the stage is set for continued progress across the space.

1.2 Report Scope

This report assesses the smart electric metering landscape to identify the gold standards of advanced metering infrastructure (AMI) deployments. This includes analysis across several business and technology dimensions. On the business side, proper pre-planning is critical to seamless deployments; this includes establishing a strategy around analytics, cybersecurity, data governance, integration mapping, and public outreach. On the technology side, much of the value behind smart meters is trapped within the data. While smart meters present inherent benefits around billing, outage management, and workforce management, analytics applications (e.g., customer experience, grid management) can significantly increase the value proposition behind smart electric metering; this is highlighted in Section 4. Section 5 discusses post-deployment considerations and recommendations, including expected operating life, opt-out program development, maintenance implications, additional value-adds, and closing thoughts.

Navigant Research, a Guidehouse company, maintains an extensive library of syndicated research reports to support this analysis. These syndicated research reports are completed through a mix of primary and secondary research. Navigant Research frequently conducts primary interviews with market participants in support of report research; recent interviews with AMI and other relevant providers will be used for this analysis as well. Relevant reports include:

- *Global AMI Tracker 4Q19* (Upcoming)
- *Energy IT & Cybersecurity* (4Q19) (Upcoming)
- *Advanced T&D Technologies Market Overview* (4Q19) (Upcoming)

- *Global AMI Tracker 2Q19* (2Q19)
- *Market Data: Smart Meter Global Forecasts* (3Q19)
- *AI and Advanced Analytics Overview* (3Q19)
- *Distribution Automation Technologies* (2Q19)
- *Big Data Management for Utilities* (2Q19)
- *Networking and Communications for Smart Water and Gas Utilities* (2Q19)
- *Navigant Research Leaderboard: Utility Field Area Networking* (1Q19)
- *Global AMI Tracker 4Q18* (4Q18)
- *Smart Gas Meters* (4Q18)
- *Networking and Communications for Smart Grids and Utility Applications* (4Q18)
- *T&D Sensing and Measurement Market Overview* (1Q18)
- *Cybersecurity for the Digital Utility* (3Q17)

Section 2
MARKET ISSUES

2.1 Market Drivers

The original electric meter was designed to provide utilities with a simple number—the sum of the electric current that flowed through the meter over a given period for billing purposes. However, as distribution grid and distributed energy resources (DER) technologies have evolved, and as computing power has been miniaturized, electric metering systems are transforming into complex connected networks of intelligent devices, fully equipped with onboard sensors, computers, and communications capabilities. The drivers discussed here propel this transformation and are anticipated to continue motivating growth in the global market for advanced metering infrastructure (AMI) deployments of all shapes and sizes:

- **Reduced labor costs:** With two-way communicating meters, utilities avoid costs associated with dispatching meter-readers, cutting utility labor costs, and helping utilities effectively manage their workforce.
- **Advanced automation applications:** Utilities are increasingly looking to use their smart meter data for more advanced automation applications, including Volt/VAR optimization, conservation voltage reduction, and fault/outage detection. Enhanced communications have further positioned smart meters to add value to an intelligent and reliable distribution grid.
- **Integrated DER:** With an increasing number of behind-the-meter demand-side generating assets, smart meters allow utilities to collect accurate data on customer generation for net metering billing and rate structures. DER smart meters also record demand-side generation to provide owners with insights into their generating performance.
- **Improved operations and reliability:** Two-way communications with meters enable more accurate outage detection and quicker service restoration. Smart meters can send last gasp messages to alert operations center personnel (or IT systems) to outages and restoration. Some meters can help utilities identify the exact location of an outage, as accurate as between two smart meters. This functionality is a key driver in areas prone to unreliable electricity access and regions vulnerable to the increasing frequency of natural disasters.
- **Improved billing accuracy:** By eliminating estimated consumption, customers are billed only for their actual usage, improving the predictability of utility revenue streams.
- **Reduced or prevented theft of service:** Smart meters can detect and record theft of electrical service, which can amount to 20% or more of total energy supply in some

markets. Theft and revenue protection are primary drivers in the emerging markets in Asia Pacific, Latin America, and the Middle East & Africa.

- **Increased energy efficiency and peak demand reductions:** Smart meters enable programs such as demand response (DR) and time-of-use (TOU) rates. These programs allow utilities to provide customers with options to promote efficient network operation during peak demand periods.
- **Improved load management:** Based on smart meter trending analysis, utility operators can gain more granular insights into customer electricity demand, which helps utilities optimize their investments in new, retrofit, or replacement network infrastructures, such as substations and transformers. Studying meter data can also provide insights into the operating performance characteristics of distribution transformers and other end-of-line assets.
- **Enhanced customer experience (CX):** By providing customers with accurate and timely data on their energy consumption, utilities are encouraging informed customer usage decisions and increased interactions between customer and utility. This enhanced experience drives up customer satisfaction while providing customers increased opportunities for energy savings. With the advancement of CX analytics, traditional solutions (i.e., home energy reports) are now being complemented with advanced tools such as disaggregation.

2.2 Market Barriers

While smart metering has an impactful set of market drivers, significant market barriers remain across the industry. The following barriers play major roles in suppressing further growth for smart meters:

- **Lack of a clear cost-benefit analysis:** Before making the relatively large investment in AMI systems, utilities will typically conduct a cost-benefit analysis; many regulatory bodies mandate this. And while many utilities have determined AMI systems to be cost beneficial investments, the results are not always positive. In Germany, for example, a 2017 study concluded that a mandated national rollout smart meter was not warranted, and that a selective approach will be used instead. Government-conducted cost-benefit analyses from the UK and Victoria, Australia, have also questioned the value of smart meter deployments.
- **High cost to deploy:** A wide-scale smart meter rollout requires significant investment of both time and capital, and for some utilities that lack resources or that do not want to burden customers with higher tariffs, the financial hurdle may hinder projects.
- **Technology challenges:** With multiple standards for meters and communications protocols available, devices can be incompatible across vendors. Going forward, utilities and vendors are looking toward interoperable solutions. Incompatibility with legacy systems may delay new investment in smart meters. Additionally, metering

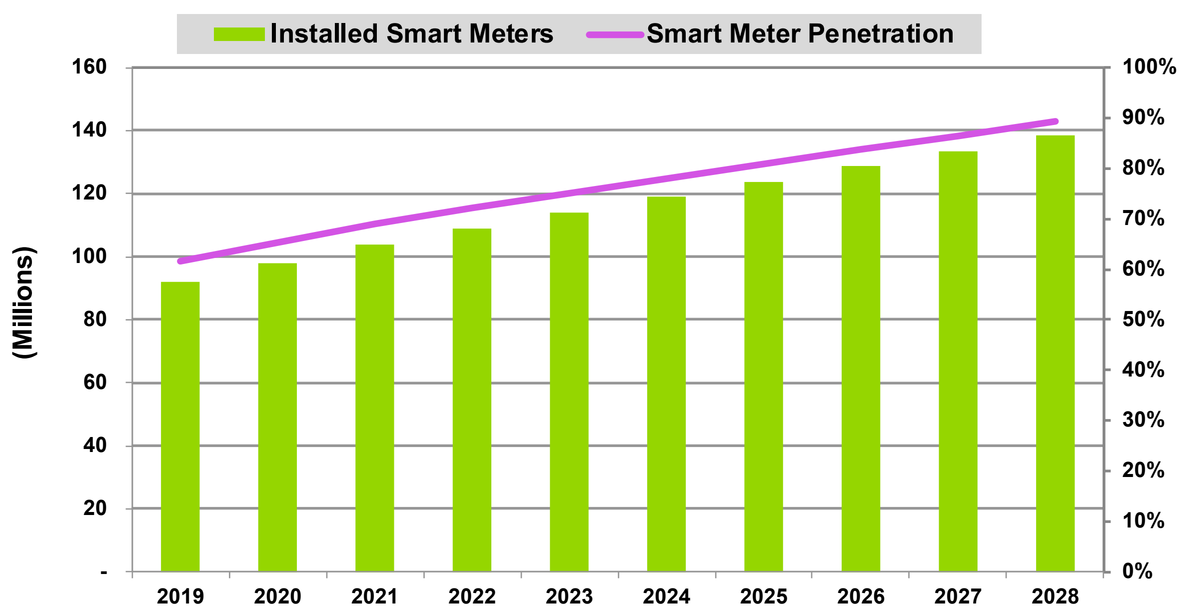
technology is evolving at a more rapid pace than ever, pushing utilities to carefully consider any systemwide investment, including smart meters.

- **Skills shortage:** Some utilities, especially midsize and smaller ones, may not have sufficient in-house competencies to support a smart meter deployment or the ongoing operations of AMI. Skilled smart meter installation labor is scarce and expensive.
- **Consumer pushback:** Vocal customers have raised privacy and health concerns related to smart meters and their communications networks, and some regulators have mandated opt-out programs to placate those concerns. This pushback is happening across the industry and may become a driver for shorter meter life cycles. This change comes as utilities target the ability to provide customers with more frequent upgrades, easing their concerns by integrating the continuous improvement of networking technologies.

2.3 Market Forecast

Navigant Research anticipates the installed base of smart electric meters will grow from 92.1 million in 2019 to 138.4 million in 2028, at a compound annual growth rate (CAGR) of 4.6%.

Chart 2-1. Cumulative Smart Meter Installed Base and Penetration Rate, US: 2019-2028



(Source: Navigant Research)

Section 3
PRE-DEPLOYMENT PLANNING

3.1 Introduction

Prior to advancing smart metering rollouts, utilities must plan and strategize to minimize project risk and streamline the deployment process. There are several high level success factors that can be researched and developed prior to breaking ground, including public outreach and communications, cost considerations, IT and analytics roadmap development, and human capital.

3.2 Public Outreach and Communications

Public outreach is a critical consideration during the pre-planning deployment process and must address communications before, during, and after project deployment. This has been shown to have a significant impact on public perception and can introduce project delays (via opposition) if not carefully managed.

Public misconception can be particularly dangerous to project outcomes, as vocal minorities can impact larger community sentiment. Common opposition points include, but are not limited to:

- Lack of project value or necessity
- Consumer privacy concerns
- Consumer health concerns (e.g., radiation)
- Safety concerns (e.g., fire, explosion)
- High bill concerns

Frequent communications and project transparency can go far in driving AMI program success. However, utilities and service providers must avoid over-communicating or communicating in ways that do not provide value to their customers. PacifiCorp has devised a five-step customer communications process to assist with its current AMI rollout:[1]

Table 3-1. PacifiCorp AMI Communications Process

Status	Timeline	Action
Pre-Deployment	Two Months Prior	Postcard letting customer know installations will be in their area

[1] Nicholas Nhede, "PacifiCorp's Smart Meter Rollout," *Smart Energy International* (2019), https://www.smart-energy.com/industry-sectors/smart-meters/pacificorp-smart-meter-rollout/.

Status	Timeline	Action
Pre-Deployment	One Month Prior	More detailed letter which provides additional detail on the installation process, along with some smart meter benefits
Pre-Deployment	One Week Prior	Phone call that customer installation is scheduled for next week
Installation	Day of Installation	Door hanger that contains additional information
Post-Deployment	One-Two Weeks After	When the smart meter is communicating on the network, a follow up postcard is sent that directs customers to go to their online portal (if available)

(Source: Navigant Research)

While the ideal mix of best practices will depend upon individual community demographics and public sentiment, there are several other common strategies:

- Consumer privacy is a top concern among customers; utilities must be transparent with the public around the level of information gathering, sharing, and storage
- Develop and employ effective and proactive social media
- Employ strict safety standards (e.g., Underwriters Laboratory certification)
- Host town halls (or similar events) to facilitate grassroot support
- Implement basic segmentation strategies for tailored communications; customer values in different communities are an essential consideration to seamless deployments
- Ongoing communications can help mitigate the impact of opposition material (typically internet accessible, unscientifically sound)
- Explain utility- and customer-level drivers behind AMI deployment with a focus on customer benefits

3.3 Smart Meter Functionality

This report focuses on smart electric meters and the economic and technological forces shaping the market. For the purposes of this study, a smart electric meter includes the following capabilities:

- Integrated intelligence (i.e., computing and data storage) enabling energy readings at frequent intervals—at least once hourly but often at 15-minute intervals
- Integrated, two-way communications between the meter and a utility's headend systems (HES), enabling remote reading and control of the meter

Although this definition is consistent with definitions maintained by most standards and governmental organizations, it is inconsistently used. In particular, the criteria of supporting at least hourly meter reading (and an associated communications network to support this functionality) has not always been true for early AMI deployments and growing international economies.

While the primary purpose of a meter is to measure power consumption, many smart meters provide a variety of power quality measurements as well, including for line voltage, current, and frequency, greatly enhancing grid troubleshooting, maintenance, and load planning efforts.

In terms of equipment functionality, there are several recommended capabilities:[2]

- Ability to measure and report:
  - Kilowatt-hour, kilovolt ampere reactive hours, and kilovolt ampere hours consumption, and daily peak kilowatt, kilovolt ampere hours, and kilovolt ampere demand
  - Instantaneous voltage and current
  - Power factor readings
- Advanced security with encryption
- Integration with utility SCADA and billing systems (customer information system [CIS])
- Load management abilities
- Multi-channel interval data recording (5, 15, 30, or 60 minute)
- Outage management support (last gasp messages, restoration tests, outage visualization)
- Remote firmware and software upgrade capability
- Remote connect/disconnect
- Tamper detection
- TOU functionality

Smart meters vary upon customer type, as residential customers and small businesses typically require single-phase meters while larger commercial and industrial (C&I) customers require polyphase devices. These devices will vary significantly in price. For example, Indiana Michigan Power reported single-phase meter prices at $91/meter, while polyphase meters were about $188.[3]

[2] Town of Tarboro, North Carolina, *Request for Proposal: Advanced Metering Infrastructure*, 2019.

[3] [3] Indiana Office of Utility Consumer Counselor, "Testimony of OUCC Witness Anthony A. Alvarez," August 2019, https://www.in.gov/oucc/files/45235%20Alvarez.pdf.

Many of the latest smart meters have advanced edge computing capabilities, with onboard computing power capable of processing data and making actionable decisions locally without the support of a centralized meter data management system (MDMS) or other data platform. These edge computing meters represent a small subset of the global smart metering market and are expected to show strong growth over the next decade.

3.4 Communications Requirements

AMI systems are made up of smart meters with two-way communications capabilities that can be remotely read in an automated fashion. Meter reads may occur every day or even many times per day. The data from the meter is then transported to the utility's network operations center (NOC), either directly (via a cellular connection) or via a concentrator or collector that then sends the aggregated data back to the NOC over a wide area network (WAN). This is known as data backhaul. The data is then fed into the utility's IT systems (MDM and CIS) or outage management system (OMS) for billing purposes, outage monitoring, and analytics functions. Smart meters are primarily connected using private networks like radio frequency (RF) mesh or power line communications, although some meters use cellular connectivity.

The communications requirements for various AMI network components vary depending on how many potential benefits of smart metering a utility is targeting. A summary of the requirements associated with the AMI network is provided in Table 3-2.

Table 3-2. Customer Communications Process

Status	Timeline	Action
Bandwidth	Low-Medium	Meter data is generally small, and reading is relatively infrequent (1 to 4 times per hour and on demand). Requirements can grow as communication frequency increases with more advanced applications. Most bandwidth-intensive exchanges involve security authentication sequences (infrequent) and firmware updates to the meter that may exceed 100 kb of data (infrequent).
Latency	Loose	Virtually all transactions can tolerate significant latencies. Real-time transactions include individual human-initiated meter reads and DR actions.
Reliability	Low-Medium	Meter reading actions can tolerate significant downtime without serious operational side effects. Meters have local storage and will not lose data unless extended outages (many hours/days) occur. If true distribution automation (DA) actions are being initiated on an AMI system, then the reliability requirement increases significantly.

Status	Timeline	Action
Security	Medium-High	Individual customer data is not necessarily operationally critical, but privacy is an important concern, especially in Europe. Spoofing and/or replication of malicious code via firmware updating mechanisms can be costly to correct. If AMI networks are used for DA, the grid could be destabilized if widespread control is compromised.

(Source: Navigant Research)

The relative importance of these attributes can evolve over time. For example, a utility may initially deploy an AMI network where the primary purpose is daily meter reads of hourly interval data from each meter. The near-area network (NAN) might be a RF mesh network using cellular service for the backhaul WAN without strict service-level agreements (SLAs) in place, assuming that even a multi-hour loss of service would not be terribly disruptive to operations. Over time, however, if the utility deploys tightly managed DER programs such as DR, sensing, or distribution automation (DA) applications over this AMI network, then it may upgrade to a private WAN or contract for a guaranteed SLA with the cellular carrier to assure availability.

3.5 Security and Risk Management

Smart meters have to potential to present a cybersecurity worst case scenario: weak endpoints, placed in physically insecure locations, and in large enough quantities so that one or two may be compromised without detection. There are security standards in place for meter data. However, industry stakeholders have indicated a heightened awareness of the vulnerabilities and the need for proactive plans if or when breaches occur.

Utilities would be wise to assume that their smart meters will be successfully attacked and plan accordingly. Smart meters are weak endpoints in large networks, placed in locations where attackers can take their time with developing approaches. They also can be purchased on the internet, so attack approaches can be developed offline before they are tried inside the AMI system.

Many smart meter vendors initially assumed that these systems did not need to be delete secure. The meter data was not particularly valuable to anyone other than the utility and the customers, and security efforts were focused on preventing energy theft. However, with the advent of two-way control for remote connect and disconnect services and DR, smart metering systems offer new avenues for malicious (or even accidental) attacks to overall grid stability or widespread disruption and nuisance.

Security is one area where IP-based system proponents have often claimed superiority. Many IP-based systems in all industries have implemented robust security. IP, however, inherently is not more or less secure than any other protocol. It simply provides a broader set of industry tools from which to build a robust security regime.

While physical attacks are less likely given embedded protection mechanisms, there is still potential for attack if the internal serial links lack sufficient protection and a common protocol is employed. Software-based attacks are typically the crux of concern for vendors, utilities, and government regulators.

Smart meters can theoretically be used to launch denial of service (DoS) attacks against AMI systems. This was evidenced in the January 2016 issue of the *Journal of Network and Computer Applications*, where the concept of a puppet attack, which is a DoS attack propagated against smart meters using wireless mesh network, was introduced.

In worst case scenarios, cascading failures could possibly be created from compromised meters that then cause upstream failures in distribution, transmission, and even generation. However, such an attack would require that quite a few protections be deactivated in each grid.

Attacks against smart meters could be simply for energy theft, which is particularly frequent factor in developing regions, or could be a means to gain entry to AMI or the entire utility smart grid. Defenses against such attacks should include resilience for when attacks succeed, and network segmentation to prevent a single meter attack from yielding widespread access to a utility's enterprise and control networks. MDM applications can identify other misuse, such as energy theft. Additionally, newer technologies such as energy metering industrial control systems (ICSs) can help isolate energy theft events that may slip past MDM applications.

No matter what cybersecurity measures are deployed in an AMI system, it is critical to base the deployments on a security architecture. The security architecture explains how the cybersecurity elements will interact to protect the AMI system.

Utilities are recommended to take an end-to-end security approach, including:

- Enhanced encryption
- Role-based access controls (devices, data collectors, MDMS)
- Audit logging and reporting
- Device and personnel authentication
- National Institute of Standards and Technology approved encryption modes and algorithms
- Security audit logging and reporting
- Employ both design-level and code-level approaches

A utility can enhance or destroy its reputation during recovery from a security incident. Control networks, such as power grids and AMIs, are an emotional topic among the media and consumers. Security incident response teams should include a person responsible for media relations. All public statements about the incident and its response should be issued by the assigned media relations expert or by executive team members who have been briefed by media relations. If the utility has separate teams for investor relations and analyst relations, their public statements about any incident should also be coordinated through the media relations specialist.

3.5.1 Use Case: Eversource

Eversource is New England's largest energy provider, serving over 3.2 million electric customers across Connecticut, Massachusetts, and New Hampshire. As part of its 2019 AMI proposal, Eversource has identified several AMI security risks and planned controls, as noted in Table 3-3:[4]

Table 3-3. AMI Security Risks and Controls

Risk	Planned Controls
Unauthorized devices may gain access to Eversource applications	Software (authentication certificates) is deployed to the meters at manufacturing and must be predefined in the headend system (HES) for the meter/device to connect.
Data in transit from the meter to Eversource may be modified or copied prior to arrival	Encryption of traffic will be used, and data will travel over private networks.
Unauthorized logical access to the Meter could result in authorized changes or software installation	Meters will require preauthorization from the HES system of all planned changes. All communications will require authentication certificates in order to accept the connection. Also access to the devices must be via the private network.
Unauthorized physical access to the meter could result in authorized changes or software installation	Meters will require preauthorization from the HES of all planned changes. All communications will require authentication certificates provided to the technician as part of the work order package, in order to accept the connection. All physical connection points on the meter must be physically locked.
Unauthorized activity may not be detected	Meter and application must have logging capabilities and will have pre-defined alerts for inappropriate activities.

(Source: Eversource)

3.6 IT Systems Integration

New systems (such as AMI, HES, and MDMS) will need to be integrated with legacy systems to ensure seamless operations (grid, customer, meter-to-cash). Poor integration can lead to delayed and inaccurate bills, among other issues.

[4] Eversource, DOCKET NO. 17-12-03RE02 Advanced Meter Infrastructure. (Navigant Resource)

Traditionally, many utilities have siloed the different segments of their business, resulting in a non-integrated solutions framework; this applies to smart metering. Holistic IT strategies may be brought to life through the integration of AMI with multiple enterprise systems, including advanced distribution management systems (ADMS), CIS, GIS, mobile workforce management systems (MWMS), OMS, and SCADA—these systems are traditionally spread across operations, engineering, IT, and finance/accounting departments. In addition to expensive and complex technology investments, reorganizational costs traditionally have prevented many utilities from integrating across departments. However, this is changing rapidly as both vendors and utilities are realizing the need for modular, integrated/interoperable software architectures.

3.6.1 Headend Systems

HES are a foundational system of AMI deployments as they perform several requisite functions including data collection and validation, device management, and network management communications.

As a more granular level, HES functionality should include:[5]

- Accept and handle meter events (event polling, event push)
- Decrypt data and ensure it is ready to be processed by the utility
- Execute meter read schedules based on received and configured schedules
- Manage data communications between smart meters and other information systems (e.g., ADMS, CIS, MDMS, OMS)
- Network gateway management to prevent the overload on network
- Perform low level functions: meter visibility and health check, topology handling, firmware update, password and key management, meter setup
- Provide a communication and data collection layer between the smart meter infrastructure and the utility
- Send operational commands to smart meters
- Store interval load data from the smart meters to support customer billing
- Support compliance reporting requirements
- Temporarily store data, ensure its delivery to MDM

[5] Iskraemeco, *System SW: Head-End System with MDM Features*, www.iskraemeco.com\files\9015\0900\3406\SEP2W.pdf.

Common modules include database, core, manager, meter access, meter reading, scheduler, reporting, alarming, aggregation, validation, estimation, web services, and import/export.[6]

These systems are intended to integrate and interface with MDMS and CIS for optimal data management practices (discussed below). The use of standards-based, open architecture systems can streamline this integration process with existing legacy systems.

3.6.2 Meter Data Management Systems

The most basic definition of a MDMS is a system that imports, structures, and stores interval data that has been gathered from AMI HES for use by other systems and applications within the utility. Recently, however, utilities are placing new demands upon their MDMSs, stretching their capabilities so they can readily work across diverse utility systems and support applications beyond the traditional meter-to-cash and CIS functions.

Utilities are recommended to install MDM software alongside AMI deployments, as these systems significantly increase the value proposition behind AMI data streams. Beyond CIS, other common and high value integration points include ADMS, GIS, MWMS, and OMS.

The latest transition in MDMS is with its enhanced interoperability across the utility-wide value chain, where meter data is used with many different systems as an essential component of realizing extended capabilities. Some vendors have elected to develop a more vertical set of solutions, where the MDMS can be sold either with several different analytics overlays or as a modular component to a streamlined operational software platform. Other vendors recognize their core competency with MDMSs and choose to partner with other vendors to offer enhanced interoperability across the value chain of utility systems.

The software as a service (SaaS) approach, where software is hosted by the software vendor or another third-party vendor, is increasingly accepted in the MDMS space. In North America, SaaS-based meter data analytics (MDA) is a common choice among utilities of all sizes, though SaaS-based MDMS has typically been restricted to small-to-medium sized municipal and cooperative utilities. However, there is growing demand for SaaS-based MDMSs, especially in emerging markets where utilities have constrained budgets and lack sunk investments in owned systems.

3.6.3 Customer Information Systems

Billing and CIS solutions provide the databases and information systems that contain all billing and personal data pertaining to utility customers, including billing rates, historical

[6] Iskraemeco, *System SW: Head-End System with MDM Features*, www.iskraemeco.com\files\9015\0900\3406\SEP2W.pdf.

power consumption, associated charges, and meter information. Billing and CIS solutions represent one of the most complicated and expensive IT applications needed by utilities.

AMI HES and MDMS require integration with CIS (advanced and legacy) to optimize billing and meter-to-cash applications. Smart meter benefits like remote connect/disconnect are significantly easier to realize with an integrated MDMS and CIS. Poor integration can lead to delayed and inaccurate bills. Integration functionality includes:

- **HES:** Facilitates the synchronization of the meter status between the AMI headend system and CIS, and enables the identification of meters that should be transmitting data to the MDM.[7]
- **MDM:** Enables near real-time exchange of information between the respective systems, such as account and meter data synchronization, and supports the ability to import readings for billing purposes, retrieve readings on demand, and trigger disconnect/reconnect actions in the headend system.[8]

As with ADMS, CIS has seen vendors move toward more modular architectures. Vendors like Oracle and Ferranti have incorporated MDM capabilities into their CIS solutions, offering integrated solutions with a singular technology stack. These systems have the benefit of a singular user interface, lower integration and maintenance fees, and higher customer engagement capabilities. For example, Oracle's Customer to Meter (C2M) solution can reduce the size of a utility's technology stack by roughly 25% when compared with separate CISs and MDMSs.

3.6.4 Additional IT Integrations

The risk, cost, integration complexities, and time to implement are all reduced by interoperability, and standards bodies are also working to ensure that systems from different vendors can be cobbled together without excessive customization. This makes managers—and regulators—more willing to commit to IT system investments. Vendors are becoming more heavily involved in the integration of their systems, performing the integration themselves or working closely with third-party systems integrators. In doing so, the vendor assumes many of the costs and risks in the integration process and ensures ongoing support for their systems.

As the need for a multitude of IT systems grows, implementation and integration can become exponentially more challenging and expensive. Vendors are responding by making their suites of systems highly interoperable and adopting modular system architectures. This allows utilities to make their investments in a stepped fashion with a

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[7] Harris Utilities, *SmartWorks Compass SOW – City of Lawrence*, 2018. https://assets.lawrenceks.org/agendas/cc/2018/04-17-18/fi_SmartWorksSOW_signed.pdf.

[8] Harris Utilities, *SmartWorks Compass SOW – City of Lawrence*.

clear path forward as they work to meet immediate needs today and simultaneously plan for future requirements and competitive pressures. For example, vendors like Oracle (with its C2M offering) and Ferranti have incorporated MDM solutions into their CISs.

Along with HES, MDM, and CIS integrations, utilities are increasingly developing modular and interoperable IT architectures. Additional integration points include:

- **GIS:** By combining GIS circuit data and MDMS interval data, utilities can configure or reconfigure system design, detect and replace failing equipment, or forecast future resource needs. They also can proactively target potential disasters and inefficiencies across a distribution system due to improperly loaded transformers and feeder line losses. This can also be achieved via an ADMS/MDM integration, with ADMS feeding GIS.[9]
- **ADMS:** Most vendors and utilities consider ADMSs to be a combination of SCADA, a DMS, and an OMS. This integrated architecture has grown in recent years to include energy management systems and DER management systems (DERMS) modules, though this is not yet universal across vendors . HES/MDM integration with ADMS (SCADA) allows for meter status and connectivity analyses.
    - **SCADA:** SCADA operators should be able to request readings from any meter or transponder and display that result.
    - **OMS:** Integration with MDM allows for more precise estimation of missing interval data. Having outage data reported from the OMS and the AMI system helps fill in possible outage gaps, creating an enhanced enterprise data-sharing process.[10]
    - **DERMS:** Integration with MDM to automate customer billing and settlement (settlements performed in minutes when validated, edited, and estimated data is available).[11]
- **MWMS:** Integration with MWMS enables automation of work orders and crew dispatch

3.7 Data Analytics

Utilities have been using analytics as long as or longer than they have been using computer systems. The transition into big data analytics in recent years has been a result of growing amounts of data, primarily from smart meters, a changing set of business goals and environmental requirements for electric utilities, and advances in analytics technology.

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[9] NISC, "Analytics and Operations," https://www.nisc.coop/utility-solutions/operations/meter-data-management/analytics-and-operations/.

[10] NISC, "Analytics and Operations."

[11] Siemens, "See Why Cities Are Proud to Be Digital," https://w3.usa.siemens.com/smartgrid/us/en/Documents/Grid_Management_DG_Derm_WhitePaper.pdf.

Analytics maturity is still in its early stages among utilities and is changing rapidly. Historically, utilities' adoption of analytics has at best been tactical, reactive, and piecemeal. When a problem arises that requires analysis as part of the solution, a business case is put together, the requisite technologies are acquired for the relevant department, and either existing staff are trained to use the new systems or new talent is hired. The net result is that data is stored in operational data marts, access to analytics technology is restricted, and analytics skills are buried in departmental siloes unnoticed by the rest of the business.

In the past, such an approach may have served utilities' requirements without too many issues—but the utility industry has changed little over the past century, and change has typically been slow. Today, a rapidly changing business environment has sharply brought into focus the industry's lack of a strategic vision for analytics.

With so many moving parts, developing a roadmap for analytics is no simple task. Navigant Research has identified a number of guiding principles (Section 3.7.1) to follow in this process, which overlap between technology and management of technology.

There is no single approach to analytics that utilities can take. Each market has a set of unique issues it must face, and each company has its own unique organization, approach to data, skills, and IT infrastructure. While a handful or organizations may take the bold step of completely overhauling their IT infrastructure so that it supports an enterprisewide data management and analytics strategy, the vast majority will have to enact incremental change.

3.7.1 Roadmap Development

The first step to creating an analytics roadmap is to understand the organization, its data and data management, IT infrastructure, culture, and skills. It must assess what is missing from the organization, and how any gaps will be filled. Best practices in roadmap development include:

- Companies must identify what areas are in the most need of analytics. It is vitally important to incorporate some quick wins (e.g., revenue protection, outage detection) in the first wave of projects to ensure the business maintains a positive view of a project.
- It is vital that the project does not lose sight of the longer-term goals of the business. It is hard to resist shortcuts that expedite the delivery of individual projects at the expense of a groupwide strategy.
- While some utilities will make a huge investment in new IT infrastructure, many will have an infrastructure that uses several technologies to strike the right balance between time-to-decision and value to the business. Batch processing will remain a

primary option for analytics, but in-memory will become more center stage, particularly if utilities transition their existing SAP estate onto a HANA platform.

- Although utilities have been slow to adopt cloud technology, analytics is a relatively active area. While a certain amount of caution must be exercised—particularly if customer and real-time operational data are involved—and regulatory obligations must be respected, the cloud is a great option for analytics programs.
    - When utilities want to embark on data discovery projects, using the cloud prevents them from having to making large upfront investments in IT. The elastic pricing of the cloud lends itself to analytics data projects; utilities only have to pay for the resource as it is needed. If a cloud-based discovery project proves successful, a utility then has the option to move analytics on-premise for production.
- Historically, the vendor selection process would be done within specific departments regardless of the requirements of the wider organization. However, utilities with a decade-long roadmap to an analytical future need to take a step back. The products that a utility will require in 10 years' time are not yet available, so it is important that vendor roadmaps align with the utility's long-term vision for analytics.

3.8 Data Governance

While core systems address certain data management challenges, the next evolution in the data management space comes from the advancement of Internet of Things (IoT) analytics platforms. These solutions include the most functionality for the process of analyzing data from connected devices: data acquisition, preparation, cleansing, storage, integration, analysis, and the delivery of insights. Advanced software systems can mitigate many of the challenges of data platform deployments when compared with outdated or homegrown systems.

Much of the new data created by a digital utility will likely come from connected devices, including smart meters. However, these devices have many characteristics, creating a great deal of complexity regarding data management:

- Device ownership varies from utility-owned hardware, such as AMI and grid sensing and controls, to customer-owned devices, including smart appliances and smart lighting systems.
- Issues from device ownership can be experienced within a utility. For example, an engineer may want to analyze voltage quality in specific parts of the distribution network alongside customer data created by a utility-led smart home initiative. Gaining access to data from the distribution and retail sides of the business is often problematic.
- Regulatory oversight also plays a role in data management. Regulators will insist utilities implement specific data security requirements for customer smart meter data.

- Data accuracy also varies across different devices. Although a utility should be able to trust the data from smart meters or phasor measurement units, the sensing equipment in smart home devices may be less robust. Consequently, utilities must have a plan in place to mitigate any problems caused by different devices giving different insights regarding the same property.

The complexity of the data involved requires important management, and the complexity of the analytics involved will surpass that of most utility data discovery projects. From the outset, utilities will have to pay close attention to model management, data management, and change management for advanced analytics to be a success.

3.8.1 Data Storage

There are many different options for data storage. For most utility IT and analytics components, there is no single solution for data storage for the industry. It is critical that utilities establish the right data management policies and IT infrastructure to allow the organization to access and analyze data from a number of different sources. The following list provides detail on different storage options and their respective benefits:

- **Data historian:** SCADA data historians will remain the primary storage solution for operational data, and different departments are likely to retain operational data marts for a number of specific purposes.
- **Data warehouse:** There are a number of tier one utilities opting for an enterprise data warehouse (EDW) strategy, where all enterprise data is shifted onto a single platform. An EDW can be an expensive purchase, but the scalability and ability to replace a large number of operational data marts makes economic sense to larger utilities.
- **Data lake:** To enable IoT to work with utility grid systems, leading vendors such as Oracle, Microsoft, and C3.ai are emphasizing the use of data lakes, which are different from traditional enterprise data warehouses. A data lake is a collection of data in original form without a predefined design or schema. This data can be repurposed on demand, providing new ways to analyze it and make it useful. Consider an application that dynamically aggregates data from smart meters, internal machines in a business process, electrical load demand signals, distributed solar and wind resources, and detailed weather forecasts to tell the grid operator to prepare for a DR event in near real time.
- **Distributed data:** Some data will not even touch a utility's on-premise data center. Data created at the edge could be stored and analyzed locally, and only relayed back to headquarters if certain criteria are met.
- **Data platform:** The next evolution in data management; software and cloud solutions that provide device or connectivity management, data analytics, and support for developing applications that control, manage, and integrate things in an environment.

3.8.2 Use Case: Green Mountain Power

Green Mountain Power (GMP) is an investor-owned utility providing service to approximately 265,000 Vermont-based customers. Following its smart meter deployment, the utility faced a fivefold increase in meter data. To maximize the value of this data, GMP worked with Cloudera to deploy a hosted data warehouse that powers both self-service (demand side management [DSM]) and operational (financial, load analysis) applications. This tool helps accelerate key processes, such as extract, transform, load, data correlation, and reporting. Although it was deployed on-premises, GMP plans to migrate certain warehouse processes to Amazon Web Services as cloud solutions enable higher efficiencies for different analytics applications.

3.9 Human Capital

Staffing is one of the most challenging aspects of utility operations—but it is central to the strategy for achieving success across both AMI and analytics rollouts. Training should include field force workers, back office staff, and call center employees.

For both AMI and data analytics projects, the first consideration is finding the right person to manage the project. At a utility, this is someone who can balance quantitative and qualitative skill sets. They will be managing different positions from different parts of the organization throughout the process. Project delays and issues often arise from lack of expertise or experience in smart metering at both the utility- or installer-level.

For post-deployment data analytics projects, a major consideration within project management is marrying data scientist knowledge and skills with specific institutional experience. There are two types of key institutional knowledge: knowledge of the organization's specific IT infrastructure and silo or domain knowledge. Finding one or more individuals that possess two of these skill sets is unlikely and would be expensive; finding someone with all three is impossible. Instead, combining a small number of well-versed data scientists with an existing utility IT staff that can write code for applications and domain experts is likely to yield more successful AMI and related analytics projects at a lower cost.

3.10 Equipment and Project Costs

According to one major smart meter vendor, basic smart meters typically cost less than $100 but lack advanced functionality and provide simple energy usage data. More advanced smart meters include remote connect/disconnect capabilities, provide voltage readings, and support TOU rates. Per this supplier, smart meter prices typically range from around $95 for enterprise deployments to around $120 for smaller deployments (less than 75,000 customers [residential]).

Table 3-4 includes average smart electric meter costs for a number of US utilities. These values were calculated using total meter costs and number of meters deployed. Most of these projects were deployed during 2012-2014 as part of the Smart Grid Investment Grant (SGIG) program; this accounts for the higher average price points.

Table 3-4. Average Smart Electric Meter Costs: US Utilities

Utility	State	Type	Price
Central Lincoln People's Utility District	OR	Political Subdivision	$271.97
City of Glendale	CA	Municipal	$268.49
City of Leesburg	FL	Municipal	$251.18
EPB of Chattanooga	TN	Municipal	$239.05
Entergy New Orleans	LA	Investor Owned	$231.41
Sacramento Municipal Utility District	CA	Political Subdivision	$211.92
Potomac Electric Power	MD	Investor Owned	$211.61
City of Fulton	MO	Municipal	$203.21
City of Lafayette	LA	Municipal	$193.48
City of Marblehead	MA	Municipal	$188.50
Stanton County Public Power District	NE	Political Subdivision	$180.66
Westar Energy	KS	Investor Owned	$179.47
New Hampshire Electric Cooperative	NH	Cooperative	$175.96
City of Fort Collins	CO	Municipal	$172.23
City of Naperville	IL	Municipal	$171.06
Navajo Tribal Utility Authority	AZ	State	$163.74
Denton County Electric Cooperative	TX	Cooperative	$161.82
Sioux Valley SW Electric Cooperative	SD	Cooperative	$157.67
Central Maine Power	ME	Investor Owned	$157.43
CenterPoint Energy	TX	Investor Owned	$155.21
City of College Station	TX	Municipal	$153.34
Black Hills Power	SD	Investor Owned	$142.31
PPL Electric	PA	Investor Owned	$137.00
Seattle City Light	WA	Municipal	$135.00
Cheyenne Light Fuel & Power	WY	Investor Owned	$130.57
Southern California Edison	CA	Investor Owned	$115.62
City of Lakeland	FL	Municipal	$115.48
Green Mountain Power	VT	Investor Owned	$110.00
City of Eugene	OR	Municipal	$107.59
City of Milford	DE	Municipal	$96.87
San Diego Gas & Electric	CA	Investor Owned	$94.30

Utility	State	Type	Price
Indiana Michigan Power	IN	Investor Owned	$91.00

(Source: Navigant Research)

There has been a significant downtrend in meter (and communications) costs since the proliferation of SGIG-sponsored smart meters in the early 2010s, as evidenced by the newer deployments of Seattle City Light, Indiana Michigan Power, and municipal utilities in College Station, Eugene, Milford. And while smart metering hardware (40%) typically presents the largest expenditure for utilities, there are also several other cost considerations, including installation (20%), systems integration (15%), network and communications (excluding NAN modules) (10%), information technology (10%), and program management costs (5%).[12]

[12] [12] West Monroe Partners, *AMI Technology Overview*, 2019

Section 4
TECHNOLOGY APPLICATIONS

4.1 Smart Meter Applications Overview

While the primary purpose of a meter is to measure power consumption, many smart meters also provide a variety of power quality measurements, including for line voltage, current, and frequency, which greatly enhances grid troubleshooting, maintenance, and load planning efforts. Most smart meters can also transmit a number of meter events such as tampering, cover off, or a last gasp event (when the meter is about to stop working due to a power outage).

Smart meters can also be used for energy efficiency programs like DR and TOU rates and support distributed generation (DG) with net metering functions. Distribution grid automation allows for automated rerouting of power to minimize outages (fault location, isolation, and service restoration, or FLISR) and optimization applications like volt/volt-ampere reactive (VAR) optimization and conservation voltage reduction (CVR).

Utilities must identify immediate areas of project value; this includes embedded capabilities (and associated benefits), along with a number of potential analytics applications. It is vitally important to incorporate quick wins. While the business needs of individual utilities will dictate the most appropriate use cases from a temporal standpoint, the typical evolution is as follows:[13]

- **Near-Term:** Asset analytics, conservation and losses, DA, meter-to-cash, revenue protection, outage detection/restoration, remote disconnect, remote meter reading, remote move in/move out
- **Long-Term:** Bill forecasting, demand management, EVs, consumer portal, home energy management (HEM), load disaggregation, outage management, TOU support

4.2 Outage Detection and Restoration

Smart meters enable more effective outage detection and restoration through embedded functionality. These capabilities have evolved and matured in recent years with the development of advanced hardware (edge computing) and software (OMS, outage analytics) solutions.

Traditionally, smart meters send last gasp and other specific state-based messages to alert operations center personnel (or IT systems [HES/OMS]) to outages and prompt restoration

[13] Landis+Gyr, *Capital Markets Day,* 2019, https://www.landisgyr.com/webfoo/wp-content/uploads/2019/01/CMD-Landis_Gyr-2019.pdf.

activity. This baseline capability is one of the foundational drivers behind most AMI deployments.

Furthermore, outages can be detected through the correlation of smart meter data in a MDMS or through grid monitoring via an ADMS or standalone OMS system. The integrated data can be analyzed to decide the likely cause and location of the fault. Work orders can then be produced for maintenance teams (and dispatched through MWMS integration), so initial remediation can be carried out through operational control of switches and circuit breakers. Customer calls will still be taken, but inbound information may also be provided by a wide range of channels from telephone response systems to websites, text messaging, and social media.

Smart meters can be used for voltage monitoring (via voltage readings), which can in turn be used to inform outage models and assist in preventative outage management. With the advancement of edge computing, new and innovative AMI meters are now equipped with hardware and software that enables the meter to effectively function as an outage sensor. The meters can communicate with each other, eliminate false outage alarms, and locate the outage as accurately as between two connected meters. The meters feed this data directly back to the utility, which can dispatch the necessary crews to repair the outage at the pinpointed location, rather than scour the network to locate it. This process can reduce distribution outages by 50% compared to traditional smart metering.

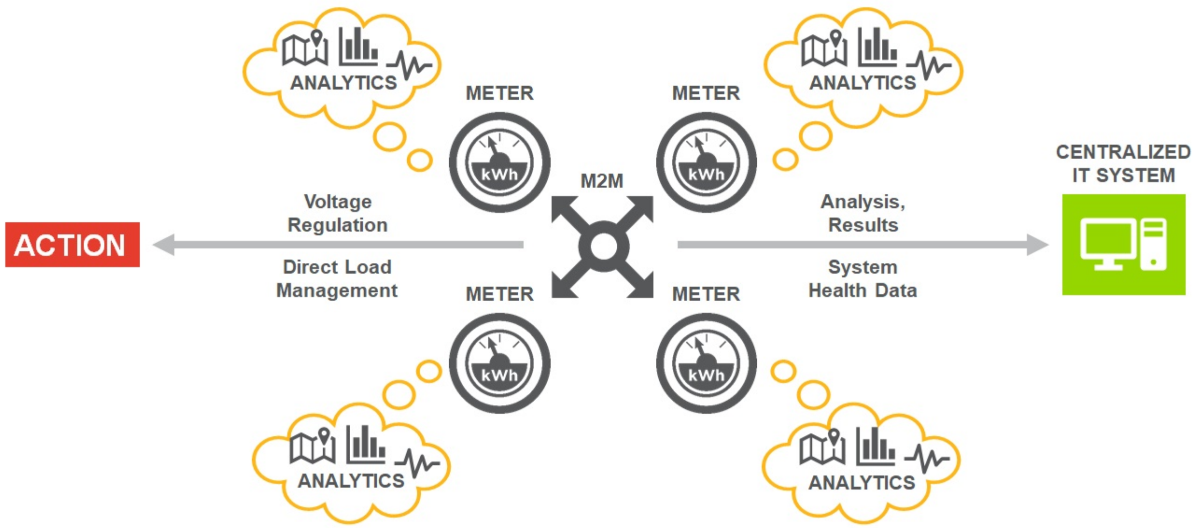
4.3 Grid Visibility and Management

As an add-on to previous AMI projects, utilities have begun to experiment with using smart meters as virtual sensors as a lower cost measure to support awareness of conditions at the grid edge. Edge computing applications of AMI installations are being developed by major vendors, and functionalities will eventually include active load and voltage control for both supply and demand side of customer meters, active DR, and integration with DA devices such as FLISR and Volt/VAR optimization.

The most advanced meters will be able to continuously calculate and analyze loads on individual distribution transformers, comparing the load to the stated capacity of the transformer. By communicating with other meters on the same transformer, the meter can identify when the transformer is getting close to overload capacity. If the meter determines that action must be taken, it can shut off controlled loads behind the transformer, increase local DG, divert the load to other transformers on the connected network, or take other actions to protect the transformer from overload.

Figure 4-1 illustrates an example of AMI edge computing with voltage regulation and direct load control capabilities.

Figure 4-1. AMI Network with Distributed Intelligence



(Source: Navigant Research)

4.4 Analytics

There are several smart meter analytics applications that reach beyond simple billing and cash-to-meter considerations. From grid operations to CX and more, utilities are using smart meter data in new ways to create additional value.

Smart meter analytics can be segmented into four distinct categories. These segments encompass the following groups of applications:

- **Grid Operations:** Meter operations analytics, outage operations analytics, grid operations planning, and real-time operations analytics. The solutions in this category are operational tools for various segments of the utility.
- **Asset:** Asset management and condition monitoring analytics for distribution assets, including asset operations.
- **CX:** DR and energy efficiency, HEM, load disaggregation.
- **Customer Operations:** Billing, front- and back-office operations analytics, customer care, and information.

4.4.1 Grid Operations

Grid management analytics is a broad field that includes use cases for grid management and planning, system control, and outage management. Meter operations analytics can also be grouped into this category. This does not include meter analytics that pertain to customer billing, energy efficiency, or DR (which are included within Section 4.4.2, “Customer Experience Analytics”).

The solutions in this category are each operational tools for various segments of the utility. These are applications in which utilities are increasingly turning to data and analytics-based decision-making, and ADMS, OMS, and MDMS. For the most part, this category of analytics is mission-critical and should be implemented in-house. However, there has been recent growth in demand for cloud solutions. Applications in this category include outage detection and prevention, damage assessment, system modeling, power quality optimization, real-time network operations and grid balancing, distributed energy resources (DER) integration, (DER) load forecasting, state estimation, AMI network visualization, meter connectivity, outage notification, root cause analysis, and damage assessment.

The sections that follow cover grid operations use cases that use AMI as primary data streams.

4.4.1.1 Connectivity Models

Utilities are increasingly looking to solidify and verify their network connectivity models. This is difficult given the rapid pace of change within transmission and distribution networks, but this fact only strengthens the need for accurate, up-to-date data models.

One AMI analytics vendor reported that between 5% and 20% of meter-to-transformer connectivity data is incorrect in utilities’ systems of record. Furthermore, a large Canadian utility cited up to 50% inaccuracy in its datasets. Along with meter-to-transformer data, phasing information is critical to utility connectivity models and DER optimization.

In situations where transformer-to-phase data is incorrect (which is often), it may be impossible to determine if customer outage events are a result of forced outages or planned interruptions. Grid reliability is still reported as a top priority for electric utilities; inaccurate models result in false information being sent to the customer, negatively impacting utility CSAT/CHURN metrics.

While most utilities still rely on manual processes to resolve connectivity data issues, this costly, time-intensive method should be replaced by predictive analytics solutions that continuously analyze asset network models to isolate potential problem areas and suggest corrective actions. Improvements in smart meter technologies have allowed for utilities to use AMI data to improve connectivity models; peer-to-peer AMI communications and advanced analytics can provide situational awareness to support network connectivity and phase detection:

- **Meter to Transformer:** Utilities can use interval and voltage data to identify mis-mapped meters. Meter-to-transformer mapping is critical for theft detection, outage detection, high impedance/safety issues, and transformer load management.

- **Phase Identification:** There is a knowledge gap among utilities in what phase customers are connected to. It may be impossible to determine if customer outage events are a result of forced outages or planned interruptions. Utilities can apply machine learning algorithms to existing voltage AMI data to accurately predict incorrect phase connectivity and correctly classify meters according to their phase.

Utilities are clamoring for predictive analytics and situational awareness within their networks—targets that can only be optimally achieved if spatial, logical, and network relationships are defined and true. This ultimately relies on a thoughtful AMI, data analytics, and data management strategy.

4.4.1.2 Load Forecasting

Utilities are turning to smart meter data to assist with both their traditional and DER load forecasting solutions:

- **Load Forecasting:** Using aggregated meter data, utilities can reduce the cost of load research, which is the periodic measurement and analysis of large samples of consumers. The goal of such research is to determine the consumption characteristics (also known as load shapes) used to allocate operations and maintenance costs in the regulatory process. More sophisticated analysis can be performed to assess system load patterns to be used as an input to investment in infrastructure improvements.
- **DER Forecasting:** DER analytics support utilities in planning and forecasting (or micro-forecasting) DER. These solutions offer the ability to analyze and predict disparate scalar and time-series datasets from DER assets and smart meters. DER can cause tremendous disruptions to traditional supply and demand patterns and heavily affect the processes of resource, capital, and operational planning. Utilities need to be able to understand and forecast DER-affected demand and DER output, and to understand and predict its locational effects on the grid to effectively perform these processes.

Smart meters provide a number of valuable data streams for load forecasting:

- Load profile
- Peak demand
- Bidirectional net metering
- Power flow measurements on distribution transformers and feeders

Load forecasting engines can generate real-time and forward-looking forecasting at a granular (household) level and then aggregate that up through the system. This enables more precise long-term planning (e.g., identify when peaks are occurring). This is particularly important as solar and EVs shift load profiles.

Furthermore, innovative utilities are now combining traditionally siloed data streams to enable new capabilities, such as storm prediction, to assist with load forecasting. Oracle recently released a DERMS module for its long-standing Network Management System, which has AI and machine learning built in. Oracle believes its product will help take data out of siloes and improve efficiency by allowing the real-time modeling of utility networks. One of its highlighted use cases is applying machine learning to data from smart meters, weather forecasts, SCADA, and other IoT devices to reliably predict future storms and alter supply and demand.

4.4.1.3 Outage Analytics

Data analytics allow utilities to vastly improve outage detection and management processes, resulting in improved performance metrics for SAIDI, CAIDI, MAIDI, and MAIFI. This can be achieved through an ADMS (or standalone OMS) or an outage analytics package, all of which run at a higher degree when integrated with the HES/MDMS. There are several major OEMs and a few smaller players that offer high value outage analytics solutions. The following is a vendor solution profile and utility use case:

- **Vendor Example:** ABB's Outage and Mobile Workforce Analytics solution enables executives and managers to make better operational decisions, improve network reliability, and optimize workflow efficiencies. Outage Analytics helps utilities understand the status of the network and changes to the system, enabling intelligent decisions during planned outages, unplanned outages, and major storm events. It provides insights on current and historical events for reliability and customer satisfaction improvements and enables communication of key restoration information to both internal and external stakeholders.
- **Utility Example:** As part of the Initiative, the Sacrament Municipal Utility District (SMUD) implemented several analytics solutions to manage the CX during outages and provide billing and usage notifications. For its outage notification sub-initiative, SMUD integrated its OMS with its Interactive Voice Response system, as well as customer survey data retrieved after outages. Specifically, SMUD improved accuracy around customer outage notifications and provided specific estimates for restoration times (previously, a generic amount of time was given to all customers receiving a notification). By using SAS for data analysis, the results of this specific project included reduced calls during outage events and increased customer satisfaction reports.

4.4.2 Customer Experience

CX analytics rest primarily on DSM applications; this includes applications for integrated DSM (HEM, load disaggregation). Solutions in this area lend themselves well to cloud-hosted models, as most data is collected from the demand side of the meter and is not as sensitive as grid operations or billing data. Generally, these applications are not mission critical.

4.4.2.1 *Home Energy Management*

Smart meter data can be viewed of as the foundation for most CX analytics and energy insight solutions. HEM began with the rise of Opower (now Oracle) and its popular home energy reports. These multi-channel customer communications provide energy insights based on smart meter data (or non-AMI data [less granular]). Energy insights include consumption data, high bill alerts, neighborhood comparisons, and increasingly, load disaggregation.

Using proactive alerts and notifications has become one of the most popular and widely deployed tools within the HEM space. This capability allows utilities to send alerts based on triggers, such as a peak day event or upcoming high bill or outage. The method of notification can range from email and automated phone calls to SMS text message and push notifications through mobile applications. Oracle (Opower) cites that its alerts have seen open rates in excess of 50% for both notification types. Compared to the industry average open rate of 20%, the value proposition of proactive alerts in supporting digital adoption of HEM technologies is clear.

The issue for utilities and other HEM solutions providers is how to skillfully organize and analyze data in ways that continue to unlock enduring value for customers. The software tools and approaches from a decade ago must give way to ones that provide deeper insights and can support more personalized customer engagements. When a customer engages with a utility, that customer expects every touch point—phone, online, mobile, or social—to be backed up by robust information about their home or whether the home supports an EV with charging or has rooftop solar. While HERs are still widely used by utilities across the US, technology evolution has led way to more advanced applications, such as load disaggregation.

4.4.2.2 *Load Disaggregation*

Load disaggregation solutions provide utilities and their customers with appliance-level energy usage information that can help prioritize energy-savings efforts. This can be viewed as the next-generation of home energy reports, with more granular insights and usage information. These solutions apply machine learning algorithms to AMI interval data to look for appliance signatures or usage patterns. While still a relatively new analytics application, there are a number of notable vendors developing these solutions in preparation for the influx of engaged utility customers.

Load disaggregation's value lies in what services can be built atop simple information regarding device consumption patterns. There are multiple use cases that can be spun out of a disaggregation algorithm: DR, security, home automation, energy efficiency, HVAC maintenance, and appliance sales.

There are two types of disaggregation vendors: software-only and hardware plus software. Hardware vendors typically have some form of clip-on meter that is attached to a fuse box that can analyze data in real time. Software-only vendors rely on smart meter data. While this software-only approach significantly reduces cost, vendors must work with less frequent data samples: smart meter readings vary from 15 to 60 minutes; a clip-on meter can provide readings every second.

Beyond the benefits to the customer, utilities are also looking to load disaggregation data to assist with their call center operations. For example, Bidgely recently enhanced its solution for utility call centers; the company's AI-powered CARE platform provides customer service representatives with appliance-level usage information that gets to the heart of an issue and can shorten call times and improve customer satisfaction because the data is richer and specific to the home (customer operations analytics overlap).

4.4.2.3 Customer Segmentation

Customer segmentation is the process of cataloging customers into groups, or classes, based on similar behavioral habits, demographics, and socioeconomic statuses, among other factors. Utilities can apply machine learning techniques to AMI datasets in order to split up customers through various archetypes.

Segmentation has traditionally been a manual and time-consuming process. This has led many utilities to barely invest in segmentation or to ignore it entirely. While this capability is not well established today, the process is gaining popularity among utilities as a customer operations analytics application.

For utilities, proper customer segmentation can facilitate higher levels of program participation and better inform product development and communications teams. By creating personalized user experiences, utilities can boost its customer satisfaction scores and lower its operating cost through more efficient touch point interactions.

Companies like AutoGrid, Oracle (Opower), and Uplight (Tendril) offer tools that can help utilities streamline their segmentation processes and transform a simple segmentation tree into one with potentially 100 end segments or more. Segmentation data can then be used to enable customer-centric capabilities like next best action, personalized alerts, content, and notifications, rewards programs, and targeted web marketing.

Hydro-Québec, the sole electricity distributor in Quebec, moved forward with a residential segmentation project in early 2017. The project was conceived to enable paperless billing options for all its customers. By collaborating with an integral third-party and applying behavioral economics principles to a massive amount of customer and operational data, Hydro-Québec created five individual customer segments (Innovative Investor, Continually Connected, Totally Tech, Sensible Saver, Simple Service), along with segment-specific strategies to improve paperless bill adoption rates. Hydro-Québec can now use this customer segmentation data to enable additional capabilities.

4.4.3 Customer Operations

Customer service improvements are a strategic imperative for utilities everywhere. Competition is increasing in many liberalized markets, forcing utilities to improve CX, improve customer retention, and develop new customer services beyond basic power supply. However, CX improvements are not restricted to competitive markets: regulators around the world are flexing their muscles to force utilities in monopoly markets to improve the CX.

Many utilities are turning to analytics to help improve customer operations, and the market is seeing diverse use cases that support utility billing, CIS, and customer service and call center operations. Many of these solutions—except for billing—are being offered as a cloud-hosted solution, or SaaS; acceptance for this model has been strong within utilities.

4.4.3.1 Fraud Detection

Theft (non-technical losses) reduction is a primary driver behind many AMI deployments. It is often one of the first use cases that was realized, as smart meters enable immediate low level protection. Compounded with MDMS and/or theft analytics, the value proposition increases dramatically. With more accurate and timely consumption data, utilities can use analytics to detect increasingly sophisticated attempts to defraud electricity suppliers. Low level non-technical loss (NTL) analytics are often provided with MDMS; advanced NTL analytics are typically procured as standalone solutions. Machine learning is increasingly being used to reduce false positives and identify previously undetected methods to defraud suppliers.

4.4.3.2 Contact Center Next Best Action

Contact center next best action allows utilities to surface a recommended next best action for its customer service representatives, based on what is known about that customer. This process can be supported with customer segmentation data (it typically requires AMI data stream), though next best action also integrates a number of additional data points in its analysis. These capabilities provide benefits to the utility through cost-of-service reductions and increased program participation and to customers in the form of higher quality customer service.

4.4.3.3 360-Degree View of Customer

360-degree view of customer refers to managing all customer information (AMI, CIS, CRM, MDMS) in one place and making it accessible to a business user for analytics and customer research. By organizing and integrating data by customer preferences, expectations, and sentiments, utilities can achieve greater visibility into their customer base and facilitate next best action capabilities

4.4.4 Asset Analytics

Asset analytics includes all analytics grounded upon improved asset management for utilities. This is a quickly growing field; there are many benefits to improving asset management in a utility, whether it be by improved maintenance, more informed asset life cycle management, asset monitoring, and predictive maintenance of assets.

Broad applications include monitoring physical assets, optimized maintenance scheduling, field information tools, machine health and failure prediction, asset modeling, and asset tracking. While this traditionally has been an exercise at the generation and transmission level, utilities are increasingly realizing positive value propositions at the distribution level. Smart meters can be considered sensors in the low voltage network, providing monitoring capabilities at the grid edge and providing operations centers with information on voltage and outages.

An instrumented distribution network with smart meters and DA can maintain detailed actual versus planned profiles of assets. To attain a holistic vision on the state of the asset base, asset management systems require interfaces between multiple systems, such as MDMS, ADMS, MWMS, CIS, and OMS.

4.4.4.1 Asset Performance Management

Asset performance management provides much of the insight for utilities seeking to develop condition-based and predictive asset management strategies. Predictive maintenance analytics is a rapidly growing field that promises to optimize both capital and operational expenses for utilities. Condition-based analytics systems for assets are emerging that will help operations personnel see a failure before it happens, preventing outages and saving millions of dollars for the utility industry. In addition to these benefits, it can decrease the number of truck rolls by limiting the need for scheduled asset maintenance.

Condition-based asset maintenance is enabled by the capability to monitor assets in real-time or near-real-time, providing more accurate and timely information on replacement or service needs. Condition monitoring is enabled by the spread of sensors (including smart meters and connected power electronics) and communications in the grid, in addition to an informational backbone that can make algorithm-based determinations on asset health and performance. Maintenance is performed as the need arises when one or more indicators show equipment performance is deteriorating or that an asset is going to fail.

Section 5
POST-DEPLOYMENT CONSIDERATIONS

5.1 Operating Life

Vendor specifications typically cite the lifespan of smart meters at 20 years. This is largely overestimated, as technology obsolescence and security issues are more likely to force replacement rates between 12 and 15 years.

According to one major AMI vendor, there has been a notable shift toward shorter replacement timelines over the past decade. Newer technology and greater power/functionality have incentivized 12–15-year timeframes in lieu of traditional vendor recommendations of 15–20 years.

This all being said, there is the potential for more advanced smart meters maintaining longer lifespans. For these recently-deployed smart meters, enough time has not passed to determine if there are comparable examples of meters meeting or exceeding their projected asset lives.

According to Navigant Research's *Global AMI Tracker*, there are a few US utilities now advancing second generation smart metering. Examples include:

- **Arizona Public Service's** Elster smart meters varied in their operating lifetime; Phoenix area customers' meters were replaced in 7 years, while some residents' meters were replaced as early as 2 years (e.g., Sedona, Verde Valley).
- **PPL Electric** finished its initial AMI deployment in 2004. The smart meter replacement project began in December 2016 and is expected to be completed by 2019.

There are also varying expected lifetimes across first-generation deployments. Examples include:

- **First Energy:** Per Bennett Gaines, *VP & CIO,* "These devices are now computers, and so they have to be maintained. They don't have the life of an existing meter which is 20–30 years. These devices have a life of between 5–7 years. And so the challenge that the industry has is making sure they maintain their smart grid environment, not neglect it."[14]
- **Indiana Michigan Power** chose an AMI capital depreciation schedule of 15 years.[15]

[14] K.T. Weaver, "Congressional Testimony: 'Smart' Meters Have a Life of 5 to 7 Years," (2015) https://smartgridawareness.org/2015/10/29/smart-meters-have-life-of-5-to-7-years/.

[15] Indiana Office of Utility Consumer Counselor, "Testimony of OUCC Witness Anthony A. Alvarez," August 2019, https://www.in.gov/oucc/files/45235%20Alvarez.pdf.

- **Kentucky Utilities (KU) and Louisville Gas & Electric (LG&E):** In August 2018, Kentucky's Public Service Commission for the Commonwealth of Kentucky denied KU and LG&E's request to deploy smart meters. The Commission was unable to verify the expected operating life of 20 years and rejected the vendor recommendation without more appropriate support.
- **City of College Station, Texas:** "If the meters have a life of 11–12 years, we'll likely break even on the costs and benefits of the new system. Any shortfall would simply be the cost of doing business and providing better service."[16]

While Navigant Research expects most utilities to employ a 12–15-year operating life, there are a number of new deployments that are still advancing 20-year timeframes. For example:

- **Memphis Light, Gas and Water (MLGW):** "MLGW's existing electric meters last an average 25 years. Electric and gas smart meters are designed to last 25 years, while water smart meters have a 15-year life expectancy."[17]
- **AEP Texas:** "To provide some perspective, under typical operating conditions, an individual meter would transmit for approximately 45 minutes over a 20-year operating life."[18]

There are several business and technology factors that will ultimately determine the lifespan of electric smart meters, such as weather conditions, availability of new technologies, analytics roadmaps, communications requirements, and more. To maximize the value of first- and second-generation smart meter lifespans, careful planning and long-term roadmap development is recommended.

5.2 Opt-Out Programs

The development of opt-out programs has been addressed in a myriad of ways by electric utilities across the nation. This often-controversial project element revolves around offering customers a means of opting out of receiving a smart meter. Best practices in opt-out program development will depend upon community demographics, total project costs, public perception/education/awareness, expected opt-out rates, among others. The following is a subset of recent utility and program examples:

[16] City of College Station, "CSU's Smart Meters Will Be Safe and Secure," https://blog.cstx.gov/tag/smart-meters/.

[17] Memphis Light, Gas and Water, "Smart Grid FAQ," http://www.mlgw.com/smart-grid/smartgridfaq.

[18] AEP Texas, "Frequently Asked Questions and Answers," https://www.aeptexas.com/save/residential/SmartMeters/FAQs-and-Answers.aspx.

- **Nashville Electric Service (NES):** NES requires customers pay $141 upfront for the cost of an analogue electric meter; this is in addition to $32 per month for meter reading expenses[19]
- **Arizona Public Service (APS):** On September 12, 2017, APS received approval from the Arizona Corporation Commission to charge residential customers a fee to voluntarily opt out of receiving an advanced meter and to instead receive a non-AMI meter. Through a settlement agreement with stakeholders and interested parties, the original APS proposal was reduced from a one-time fee of $70 plus $15 a month, to a one-time fee of $50 plus $5 a month.[20]
- **Hawaiian Electric:** On June 21, 2018, Hawaiian Electric Company filed an application requesting approval to implement Phase 1 of its Grid Modernization Strategy, which the Hawaii Public Utilities Commission PUC previously approved on February 7, 2018. Phase 1 consists of advanced meter deployment on an opt-in basis and the deployment of related software and telecom systems.[21]
- **Xcel Energy (Minnesota):** On May 31, 2018, the Minnesota PUC approved a pilot program for residential time-of-use rates proposed by Xcel Energy. The program is scheduled to begin in early 2020 and will be deployed to 10,000 customers. The program uses an opt-out design and will offer three different rates: an on-peak rate, a mid-peak rate, and an off-peak rate.[22]
- **Clallam PUD:** In March 2019, district commissioners voted to approve a revised residential meter policy that lowers the opt-out fee from $30 to $15 per month.[23]
- **Orange and Rockland Utilities (O&R):** Opt-out customers will be provided with a digital, non-communicating meter that also is tested and approved by the New York State Department of Public Service. Meters will be read in person by a meter technician each month; costs will be directly incurred by opt-out customers. “The New York State Public Service Commission has approved a manual meter reading fee of $15 per month for a customer opting out of both electric and gas service smart meters from O&R, and a $10 per month charge for electric smart meter opt outs only. The

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[19] Carley Gordon, “Residents Concerned of NES Smart Meters,” https://www.wsmv.com/news/residents-concerned-of-nes-smart-meters/article_075b4024-b3e0-11e9-af85-df097edc1aa9.html.

[20] Federal Energy Regulatory Commission, *2018 Assessment of Demand Response and Advanced Metering*, https://www.ferc.gov/legal/staff-reports/2018/DR-AM-Report2018.pdf.

[21] Hawaiian Electric, “Grid Modernization Technologies,” https://www.hawaiianelectric.com/clean-energy-hawaii/grid-modernization-technologies/grid-modernization-strategy.

[22] Federal Energy Regulatory Commission, *2018 Assessment of Demand Response and Advanced Metering*.

[23] Rob Ollikainen, “Clallam PUD Lowers Cost of Smart Meter Opt-Out and Adds Self Read Option,” *Peninsula Daily News*, March 29, 2019, https://www.peninsuladailynews.com/news/clallam-pud-lowers-cost-of-smart-meter-opt-out-and-adds-self-read-option/.

meter exchange fee is only applied if a customer receives a smart meter and then chooses to opt out after the smart meter has been installed."[24]

It is common to require opt-out customers to incur the operating cost of continued meter reading. This framework has been employed throughout most smart meter programs across the US. While some utilities also require a one-time upfront fee, this should be mitigated in situations where public opposition or pushback is high to help foster more positive public sentiment. To disincentivize potential opt-outs, those customers who do opt-out should be ineligible for future rate reductions based on cost savings from installing the AMI meters.

5.3 Maintenance

One of the major workforce implications of AMI deployments is the reallocation of mobile resource needs, most notably meter readers. With the networked nature of smart meters, the role of meter readers is greatly reduced within utility organizations. Rather than offloading these often-entry-level workers, utilities should look to retrain these workers to other positions of increasing responsibility within the organization. This helps mitigate change management concerns and can buffer against internal, organizational strife/pushback. Layoffs, whether small- or large-scale, can elicit degrees of public or internal conflict.

Depending on opt-out program frameworks, a limited number of meter readers will need to be retained for remaining manual reads.

5.4 Additional Value-Adds

Beyond the large and growing number of data analytics and embedded device-level applications/benefits highlighted in Section 4, new use cases continue to emerge and are providing real value to utilities and their customers. This includes:

- **Advanced Outage Management:** While there is overlap with outage analytics, advanced outage management is a broader term that includes solutions like outage mapping and outage notifications. Outage mapping is an incredibly valuable tool from a call center resource perspective. Enabled with self-reporting and automatic restoration capabilities, this solution (smart meter is a primary data stream) can dramatically reduce the number of outage-related calls.
- **Customer Service and CRM:** Smart meter data allows utilities to better understand their customers by generating granular energy usage information. When combining this with CIS and CRM systems, the value propositions increase around billing, call

[24] Francis Ruth Harris, "O&R Rolls Out Smart Meters Saying They Emit Fewer Radio Waves than Cell Phones," *The Chronicle*, September 4, 2019, http://www.chroniclenewspaper.com/news/local-news/or-rolls-out-smart-meters-saying-they-emit-fewer-radio-waves-than-cell-phones-BL490047.

center resources, customer satisfaction, and customer service. Disaggregation has proven to be an incredibly value tool within the CX space as well, though is still relatively new at present.

- **New Products and Services:** Development of personalized products and services through segmentation (warranties, rebates, product upgrades). AMI data is the primary data stream for segmentation solutions.

5.5 Conclusions and Recommendations

The adoption of electric smart meters by utilities is part of a long-term technology transformation to create a more intelligent grid. The rate of adoption will vary by region, state, and utility, but smart meters are well on their way to becoming the norm. The following is a list of high level conclusions, takeaways, and recommendations:

- **Analytics** presents the next frontier of smart metering, as there is immense value often trapped in utility servers. From grid operations to CX and more, utilities are using smart meter data in new ways to create additional value.
- Basic **smart meters** typically cost less than $100 but lack advanced functionality and provide simple energy usage data. More advanced smart meters include remote connect/disconnect capabilities, provide voltage readings, and support TOU rates, among others. Per an unnamed supplier, smart meter prices typically range from around $95 for enterprise deployments to around $120 for smaller deployments (less than 75,000 customers).
- **Communications** requirements for various AMI network components vary considerably depending on how many potential benefits of smart metering a utility is targeting data management
- Employ strict **safety** and **security** standards at the hardware, software, and network level:
    - **Hardware:** Standards certification (Underwriters Laboratory certification), embedded device security, device authentication, encryption capabilities, ruggedized equipment
    - **Software:** Design-level and code-level approaches, energy metering ICSs, device and personnel authentication, security overlays on legacy systems, patch management
    - **Network:** Network segmentation, redundant or backup communications routing (using different physical layers)
- **Public outreach and communications** (before, during, after) is a critical success factor in the planning process, as public misconception can be particularly dangerous to project outcomes. Opposition points tend to revolve around cost, privacy, and safety. Frequent communications and project transparency can go a long way.

- **Training** should include field force workers, back office staff, and call center employees. For both AMI and data analytics projects, the first consideration is finding the right person to manage the project. At a utility, this is someone who can balance quantitative and qualitative skill sets. For post-deployment data analytics projects, underneath project management, a major consideration is marrying data scientist knowledge and skills with specific institutional experience.
- Vendor specifications typically cite the **lifespan of smart meters** at 20 years. This is largely overstated, as technology obsolescence and security issues are more likely to force replacement rates between 12 and 15 years.
- Utilities have traditionally employed pilot programs to help mitigate project risk as they explore technologies and develop best practices.

Section 6
ACRONYM AND ABBREVIATION LIST

ADMS .... Advanced Distribution Management System

AI .... Artificial Intelligence

AMI .... Advanced Metering Infrastructure

AMS .... Asset Management System

APS .... Arizona Public Service

C&I .... Commercial and Industrial

C2M .... Customer to Meter

CAGR .... Compound Annual Growth Rate

CAIDI .... Customer Average Interruption Duration Index

CIS .... Customer Information System

CRM .... Customer Relationship Management

CVR .... Conservation Voltage Reduction

CX .... Customer Experience

DA .... Distribution Automation

DER .... Distributed Energy Resource Management System

DERM .... Distributed Energy Resource Management Systems

DG .... Distribution Generation

DMS .... Data Management System

DoS .... Denial of Service

DR .... Demand Response

DSM .... Demand Side Management

EDW .... Enterprise Data Warehouse

EV .... Electric Vehicle

FLISR .... Fault Location, Isolation, and Service Restoration

GIS .... Geographic Information System

GMP .... Green Mountain Power

HEM .... Home Energy Management

HES .... Headend System

HVAC .... Heating, Ventilation, and Air Conditioning

ICS .... Industrial Control Systems

IoT .... Internet of Things

IP .... Intellectual Property

IT .... Information Technology

LG&E .... Louisville Gas & Electric

KU .... Kentucky Utilities

MAIDI .... Meter Data Analytics

MAIFI .... Momentary Average Interruption Frequency Index

MDA .... Meter Data Analytics

MDM .... Meter Data Management

MDMS .... Meter Data Management System

MLGW .... Memphis Light, Gas and Water

MWMS .... Mobile Workforce Management System

NAN .... Near-Area Network

NES .... Nashville Electric Service

NOC .... Network Operations Center

NTL .... Non-Technical Loss

O&R .... Orange and Rockland

OMS .... Outage Management System

PUC .... Public Utilities Commission

RF .... Radio Frequency

SaaS .... Software as a Service

SAIDI .... System Average Interruption Frequency Index

SCADA .... Supervisory Control and Data Acquisition

SGIG .... Smart Grid Investment Grant

SLA .... Service-Level Agreement

SMUD .... Sacramento Municipal Utility District

T&D .... Transmission and Distribution

TOU .... Time-of-Use

VAR .... Volt-Ampere Reactive

WAN .... Wide Area Network

UK .... United Kingdom

US .... United States

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SCOPE OF STUDY

Navigant Research has prepared this report to assess the smart electric metering landscape and identify the “gold standards” of advanced metering infrastructure (AMI) deployments. The report’s purpose is to present an overview of smart electric meter market dynamics, technologies, applications, benefits, and more. This includes analysis across several business and technology dimensions.

SOURCES AND METHODOLOGY

Navigant Research’s industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Navigant Research’s analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Navigant Research’s analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst’s industry expertise, are synthesized into the qualitative and quantitative analysis presented in Navigant Research’s reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

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NOTES

CAGR refers to compound average annual growth rate, using the formula:

$$CAGR = (\text{End Year Value} \div \text{Start Year Value})^{(1/\text{steps})} - 1.$$

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2019 US dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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[25] On October 11, 2019, Guidehouse LLP completed its previously announced acquisition of Navigant Consulting Inc. In the months ahead, we will be working to integrate the Guidehouse and Navigant businesses. In furtherance of that effort, we recently renamed Navigant Consulting Inc. as Guidehouse Inc. We will continue to perform as proposed during and after this consolidation, using the same personnel and methods described in this report.