Guidehouse INSIGHTS

White Paper

AI at the Grid Edge

How Inside-the-Meter Analytics Drive Value at the Grid Edge

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Introduction

The proliferation of smart meters by electric utilities, begun in earnest a decade ago, was largely a function of simple motivations. At the regulatory level, subsidies provided under the US Smart Grid Investment Grant and EU Directives programs beginning in 2009 galvanized the US and European markets. From an operational perspective, advanced metering infrastructure (AMI) freed utilities from the process of dispatching meter readers to customer premises every month. The resulting reduction in labor costs was justification enough for many early AMI adopters. But these drivers, while still relevant, are being surpassed by a broader and more advanced set of use cases derived from increased data availability and a new generation of advanced analytics and AI enablement.

This Guidehouse Insights white paper explores how innovative applications of advanced analytics and AI are helping utilities maximize the value of their AMI investments. It also discusses how these advanced analytics and AI applications are being more seamlessly embedded into the AMI hardware and software operating at the grid edge, helping provide more timely, relevant, and actionable insights for customers and grid operators. The adoption of these more sophisticated architectures is growing in popularity and promises to help utilities maximize the value of smart meter deployments and the data they generate.

Exponential Growth of Smart Meter Data

An electric meter was originally designed to provide utilities with a simple number—the amount of electric current that flowed through the meter each month. However, the development of new technology and miniaturization of computing power enabled the transformation of electric meter systems into connected networks of intelligent edge computing devices, fully equipped with onboard sensors, computers, and communications capabilities.

While smart meters vary significantly in their capabilities, for the purposes of this white paper, a smart meter includes the following capabilities:

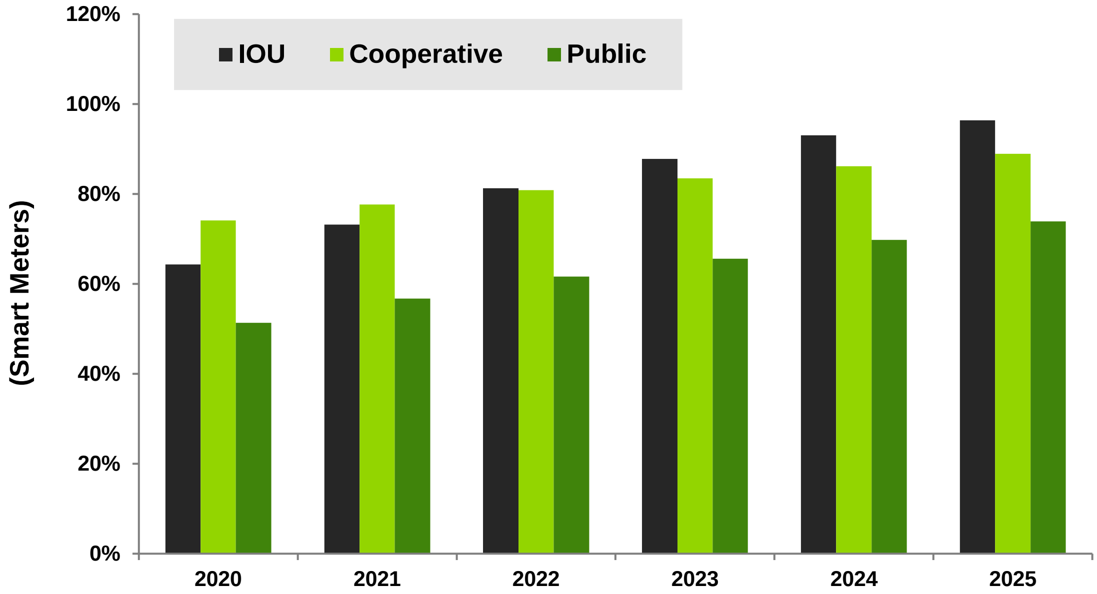
- Integrated onboard data storage and processing, enabling energy readings at frequent intervals—at least once hourly but often at 15-minute or even more frequent intervals.
- Integrated, two-way communications between the meter and a utility's headend IT systems, enabling remote reading and control (remote disconnect-reconnect) of the meter.

Although these definitions establish baseline technology requirements, advanced smart meters have evolved beyond these rudimentary capabilities. Devices can now measure and monitor the waveform in addition to energy, current, and voltage, and captures these measurements at sub-second intervals. This enhanced data availability and resolution is foundational for much of the new analytics architectures discussed throughout the white paper.

Although investor-owned utilities receive the lion's share of recognition for national smart grid development, it is important to note the strong willingness and desire among midsized utilities to similarly invest in smart metering.

The US has been at the forefront of the smart meter market, along with China and areas of Western Europe. Guidehouse Insights estimates smart meters serve nearly 65% of electric utility customers across the country and expects that penetration will approach 90% by 2028. Chart 1 highlights this growth trajectory across each utility type, with cooperatives holding the highest penetration in 2020 at 74%.

Chart 1. Smart Meter Installed Base, US: 2020-2025



(Source: Guidehouse Insights)

However, the full value proposition behind smart meter deployments has yet to be fully realized. Immediate benefits around workforce optimization, billing accuracy, and outage detection represent the tip of the iceberg in potential value creation. The disconnect stems from an underutilization of smart meter data and an underinvestment in smart meter analytics.

Utilities are inundated with massive amounts of smart meter data. For example, meter sampling collected every half-hour result in over 17,500 readings per customer each year. When applied to the growing base of smart meters Chart 1 references, and supplemented with the caveat of new data types collected at more frequent intervals, the scope of smart meter datasets grows exponentially.

The increasing volumes and types of smart meter data can seem overwhelming and are often characterized in terms like terabytes and petabytes.

The barriers behind this untapped opportunity are rapidly eroding, however. Advancements in metering technology and analytics architectures allow utilities to take advantage of larger and more granular datasets. And utilities are recognizing the value of their smart meter data with accelerated investments in advanced analytics solutions. The following section discusses the evolution of smart meter analytics and highlights the growing list of utility and customer applications.

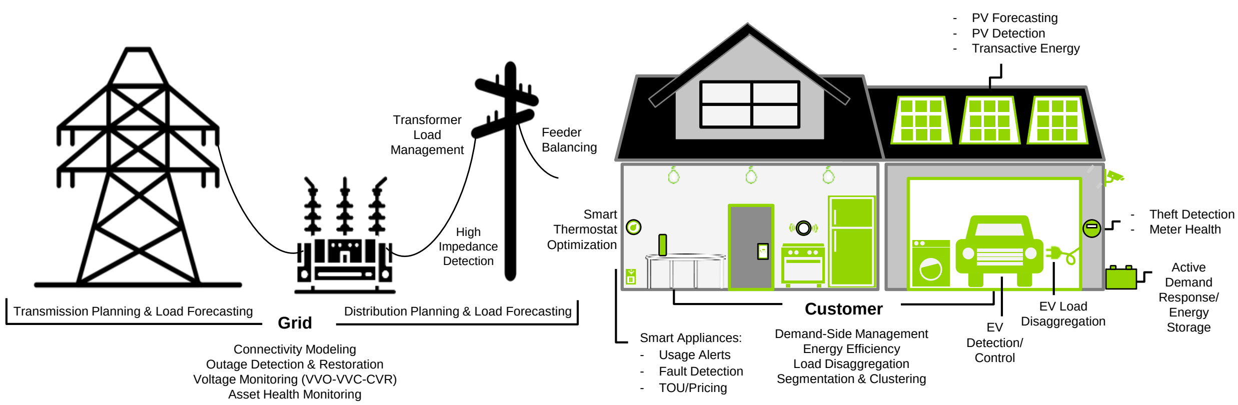
Smart Meter Analytics Unlocking Hidden Value

Early smart meter adopters were unequipped to manage large volumes and types of data flowing from meters and would capture or use only a small set of information for simple purposes like automated billing or responding to failure alerts. These are important issues or use cases, but not overly complex and not in need of deeper analytics. With the proliferation of digital and energy transformation, utilities face new challenges around customer engagement, data management, distributed energy resource (DER) integration, and more, all of which require more advanced techniques and sophisticated algorithms.

Growing List of Grid and Customer Applications

Figure 1 presents the wide range of analytics applications in use leveraging smart meter data as a primary input. This section details the key use cases being used to engage with customers, optimize the grid, and enable the integration of DER.

Figure 1. Emerging Smart Meter Analytics Applications



(Sources: Guidehouse Insights)

Utilities are turning to analytics to help improve customer experience (CX), and the market is seeing diverse use cases that support enhanced personalization and engagement. This segment encompasses a wide range of demand response (DR) and energy efficiency applications, including demand side management (DSM) program management, DER program management, digital marketplaces, and demand analytics, as well as load disaggregation and customer segmentation, both of which are featured below.

- **Disaggregated usage and behavioral insights:** Disaggregation refers to the use of data from sensors (often smart meters) to identify unique energy consumption patterns of home appliances and behind-the-meter (BTM) DER. There are two types of disaggregation vendors, software-only and hardware plus software. Software-only vendors use sophisticated AI and ML algorithms to effectively reverse-engineer AMI and make it usable without the addition of BTM monitoring equipment. This information has mainly been used to provide customers with tips on how to cut electricity usage, providing information and supporting engagement. However, 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, among others.
- **Customer segmentation:** Smart meters generate detailed load profiles that can be used to segment or catalogue customers into groups based on similar behavioral habits, demographics,

and socioeconomic statuses, among other factors. These analyses enable customer-centric capabilities such as next best action, personalized alerts and notifications, rewards programs, and targeted web marketing. For example, utilities may segment their customers based on EV ownership and apply targeted web marketing to help improve DER program enrollment.

Traditional focus areas of home energy reports and smart thermostats are giving way to more holistic solutions that combine device management, load disaggregation powered by AI and ML, and multiple engagement channels for utilities and residential customers. In the case of load disaggregation, future value lies in what services can be built atop simple information regarding energy consumption patterns.

For example, Grid4C has been successful in creating new use cases based on disaggregation data, rather than simply offering information on appliance consumption. This includes bottom-up network modeling for distribution utilities based on real-time activity at customer endpoints; an alert system that identifies and flags problems with a customer's HVAC system (currently used by Constellation); and predictive analytics for home appliances.

Smart meter analytics can also provide valuable information for network operators in support of grid management. This segment encompasses use cases across the spectrum of grid management and planning, system control, and outage management. These are areas in which utilities are increasingly turning to data and analytics-based decision-making. Specific applications include outage detection and prevention, system modeling, load planning and forecasting, real-time network operations and grid balancing, AMI network visualization, meter connectivity, and outage notification, among others. Several of these applications are detailed as follows:

- **Non-technical loss reduction:** With more accurate and timely consumption data, utilities can use analytics to detect increasingly sophisticated attempts to defraud electricity suppliers. Advanced applications operate beyond simple tamper and theft detection and feature enhanced data mining techniques and automated ticket management.
- **Load forecasting:** Smart meters have dramatically improved load forecasting techniques given the availability of detailed load profiles. Use cases have evolved from simple load forecasting to more dynamic applications around revenue, asset management, and locational pricing. And input parameters have expanded to encompass a growing number of datasets (cloud cover, wind forecasts, EV penetration).
- **Asset performance management (APM):** APM is a broad category of analytics that captures several use cases for asset monitoring, asset health, and proactive maintenance. APM analytics have historically been dependent on additional grid sensors beyond the smart meter, such as transformer monitors or line sensors. With the advent of peer-to-peer meter communications and availability of enhanced data streams, smart meter analytics can now support various asset monitoring use cases (e.g., transformer load management).
- **Connectivity:** Connectivity models provide utilities with a spatial representation of their electrical networks, including asset locations and connections. These applications analyze smart meter data to detect errors in connectivity modeling, most notably meter-to-transformer mapping and phase identification.

The development of grid-oriented use cases has traditionally been a function of enterprise IT/OT systems. One example is Oracle's DERMS module for its Network Management System; the company highlights the ability to apply ML to data from smart meters, weather forecasts, SCADA, and other Internet of Things devices to reliably predict future storms and alter supply and demand. However, improvements in metering (compute, memory) and data analytics (load disaggregation, connectivity) technologies are now enabling standalone analytics providers to compete in this market with grid-based applications powered by smart meter data.

Over the next decade, the integration of DER is one of the most pressing concerns for network utilities. The proliferation of DER, EVs, VPPs, microgrids, and more add significant complexity to traditional grid management strategies. AI-enabled analytics can be used to model network requirements under different DER adoption scenarios, detect ownership of customer-owned DER, or generate granular forecasts of DER generation and load. From detecting and predicting to modeling and forecasting, new applications are spanning the reaches of DER integration and optimization.

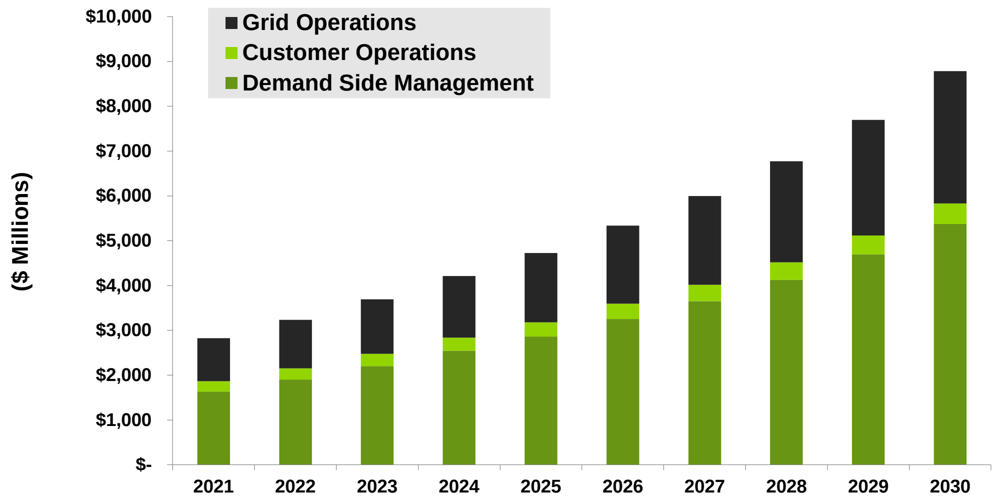
- **DER integration:** Utilities need to understand and forecast DER-affected demand and DER output to predict locational effects on the grid. DER forecasting is the most mature use case to date. More recently, DER detection tools have been developed to identify EV and PV ownership and can disaggregate load profiles using smart meter data.

Solutions providers throughout the energy value chain have been developing and promoting smart meter analytics for DER integration. Large OEMs have invested heavily in DERMS and DRMS systems with embedded analytics. Meanwhile, smaller analytics players have created micro-forecasting tools and patented algorithms for load disaggregation that enable a range of DER use cases.

This collection of use cases encompasses the market for smart meter analytics. Guidehouse Insights expects solution spending to increase over the next decade at a CAGR of 13.4% (Chart 2). DSM and energy efficiency applications are expected to lead global spending across the forecast period, growing from approximately $1.6 billion in 2021 to nearly $5.4 billion in 2030. More recently, leading utilities have come to recognize the value of using smart meter data in support of advanced network and asset management strategies. Grid-based smart meter analytics spending is anticipated to grow at a CAGR of 13.3% between 2021 and 2030.

Over the next decade, smart meter analytics spending will more than triple, growing by $6.0 billion, and account for an increasing portion of overall AMI project budgets.

Chart 2. Smart Meter Analytics Revenue, World Markets: 2020-2030



(Source: Guidehouse Insights)

With more collective experience around smart meter data and advancements in analytics, utilities recently took a cue from early adopters and set loftier objectives and expectations as a function of their smart meter investments. Vendors within the smart meter ecosystem have responded to these market shifts by offering more flexible solutions with enhanced sophistication.

Increased Sophistication of AMI Analytics

A helpful way to comprehend smart meter analytics is to consider the different evolutionary curves of this technology. Over the past decade, the pace of innovation has been rapid. From delivery models and financing mechanisms to underlying algorithms and architectures, the entire ecosystem is adapting its identity to align with a more dynamic market landscape.

These evolutionary curves both result in greater levels of flexibility and choice for utilities in their analytics strategies. Technology providers have reaped the rewards of this dual innovation through enhanced product differentiation, new revenue streams (via recurring cloud-based revenues), and more powerful algorithms.

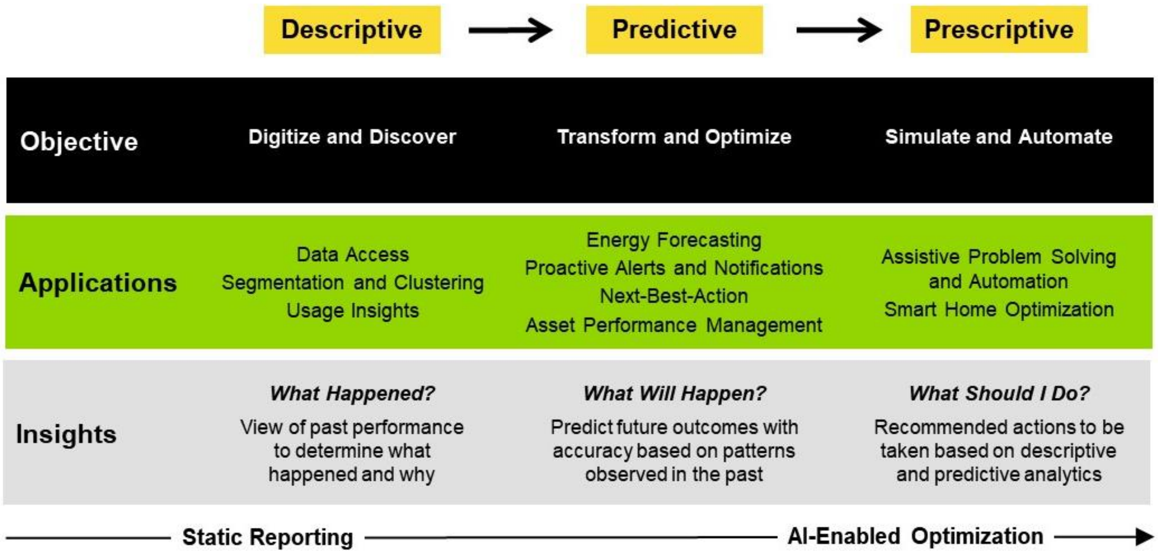
The Power of Prediction

Data analytics starts with basic reporting; this is the common sense of analytics. Data flows in from a smart meter; the data might then get stored or sent to a cloud server for applications that could be more immediate (such as outage monitoring) or for later historical purposes (like tracking asset health or billing purposes). Data reporting is important but reporting alone is rudimentary. Deeper and more insightful analysis can unlock new value.

Predictive usage insights have become a critical ingredient in transforming the customer experience from reactive to proactive.

Figure 2 provides an evolutionary framework for utilities to view smart meter analytics on a continuum. The introduction of AI and ML has spurred development and adoption of more sophisticated solutions that leverage predictive and prescriptive techniques. Although most of today's utilities fall between descriptive and predictive in their analytics capabilities, innovations occurring across the predictive and prescriptive points are driving adoption of advanced analytics models.

Figure 2. The Evolution of Data Analytics



(Source: Guidehouse Insights)

The following points along Figure 2 highlight where the action is:

- **Descriptive analytics:** Descriptive analytics entail reactive services like visualization and reporting. This is useful for teasing out approximate perspectives on large quantities of smart meter data; for example, analyzing outage statistics over a large region to identify low voltage problem areas, or segmenting customers based on similar characteristics to optimize marketing and communications processes. Utilities have plenty of experience with historical data from connected assets on the grid for modeling at this level.
- **Predictive analytics:** This level of analytics builds on descriptive patterns and attempts to predict future outcomes. For example, utilities use these approaches to forecast equipment failures and perform maintenance based on intelligent predictive algorithms. These can also be used to forecast household energy usage, or predict when appliances may begin to fail, enabling utilities to deliver proactive notifications to customers. This is the state of the art for most utilities using advanced data analytics today.
- **Prescriptive analytics:** This type of analysis reveals what actions should be taken, using simulations to automate complex decisions and pinpoint the best course of action among the pool of possibilities. This approach is rarely used within the utility sector today, though it holds great promise because it provides more surgical precision, such as promoting home energy savings through prescriptive insights, than predictive analytics alone.

The transition from descriptive to prescriptive unlocks valuable insights and enhanced benefits for utilities and their customers. For household appliance malfunctions, descriptive analytics can only let a customer know when something has already failed. Predictive analytics enable proactive notifications informing the customer when something may fail. Finally, prescriptive analytics closes this loop in recommending a set of corrective actions. This progressing sophistication can open up new engagement channels and facilitates higher levels of customer trust and satisfaction while simultaneously providing utilities with richer datasets to support applications like customer segmentation or bottom-up system modeling.

Digitization is no longer sufficient. Leading utilities are now transforming their businesses through AI-powered, forward-looking insights.

The Value of Flexibility

The design architectures and delivery models for utility analytics solutions have undergone a series of evolutions over the last decade. In the past, all data would have to be centrally stored and processed in an on-premise data center, and utilities would use their own staff to perform related business processes.

In recent years, driven by the imperative to take costs out of the business, many utilities have pivoted to more flexible, cloud-based architectures and delivery models. The cloud allows data management and analysis to be done centrally through offsite servers. Using a cloud-based solution, data is transmitted from devices to the cloud for analysis and commands are pushed back from the cloud to devices to perform an action. Offering numerous advantages over traditional methods of software delivery, cloud architectures reduce the cost of deploying analytics capabilities at the individual device level and allow for storage and processing of massive amounts of data.

Yet, cloud architectures and delivery models are not a panacea for smart meter analytics. With the advent of high frequency sampling and waveform data capture, transmitting larger volumes of smart meter data to the cloud will cause constrained bandwidth capacity. Furthermore, in scenarios where enhanced data processing can enable a fast, local decision, latency requirements exceed the capabilities of cloud-based architectures to deliver real-time insights.

To balance these constraints and provide utilities with more options, new architectures are pushing analytics further to the edge of the distribution network, including inside-the-meter itself. Rather than centrally collect data from smart meters, analyze it, and push back actions where necessary, localized analytics enable smart meters to analyze data in the field and act on certain results, only raising the alarm with network managers should certain criteria be met. This prevents devices from transmitting all data to the cloud, providing relief to future bandwidth issues.

The ability to perform certain analytics on the metering device itself resolves key constraints and open new pathways to proactive customer engagement.

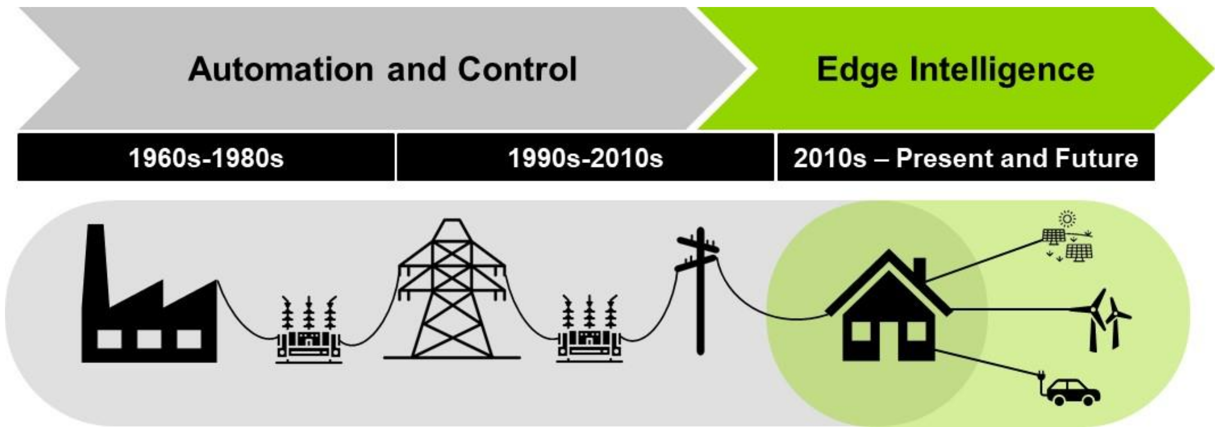
However, the consideration of different analytics architectures and delivery models is not an either-or proposition, as these are meant to be complementary pieces within the larger smart meter analytics ecosystem. As data streams continue to grow, it makes sense to have local analytics that can process and execute on enhanced data streams; this creates dual benefits of alleviating bandwidth congestion and enabling a range of low latency use cases. Cloud analytics, meanwhile, is the logical choice when processing larger pieces information to capture trends over time, or in enabling less time-sensitive use cases like customer segmentation or load planning and forecasting.

Changing the Analytics Paradigm

The edge analytics concept has a strong appeal for utilities, given the volume of assets in the field that generate data and that could benefit from making important local, time-sensitive decisions to improve operations. According to an Itron and Zpryme survey of 75 utilities, 70% of respondents report that grid edge technology is critical to their utility's future. Furthermore, 59% of respondents are already using customer-generated power and BTM energy efficiency as part of their integrated resource plans.[1]

Figure 3 illustrates the extension of monitoring and control capabilities across transmission and distribution networks, culminating in the proliferation of distributed intelligence at the grid edge. It is now standard practice to enable localized decision-making at distribution substations (via SCADA), which opens the door for a new stage of the distributed computing architecture.

Figure 3. The Evolution of Grid Intelligence



(Sources: Guidehouse Insights)

The next evolution of this paradigm comes from moving key elements of smart meter analytics strategies to the grid edge and onto to the metering equipment itself.

The next wave of smart meter deployments will feature enhanced data streams and software platforms that allow these data to be analyzed and utilized in real time at the edge.

Although promising conceptually, this strategy has been slow to evolve, primarily due to the limited breadth of data streams available in many first-generation smart meter deployments, as well as limitations on processing and computing resources. Smart meters, until recently, have only been capable of basic measurements (energy, voltage, and current) collected on 15-minute, hourly, or daily time intervals. This aligns with many early smart meter analytics use cases, such as load forecasting (for grid planning) or

[1] Itron and Zpryme, "Leveraging Distributed Intelligence in an Evolving Energy Landscape," Itron, https://www.itron.com/-/media/solutions/what-we-enable/distributed-intelligence/2020_zpryme_infographic_static.pdf.

high bill projections that can be done using daily updates of interval-based usage. Hence, there was little value of processing this inside-the-meter.

This is no longer the case with advancements in next-generation smart meter technologies. Leading meter manufacturers, such as Itron and Landis+Gyr, have significantly enhanced the onboard computing power, memory, and programmability within their smart meters. This creates new data capture capabilities for sub-second data streams across energy, voltage, current, and waveform (i.e., enhanced data). The analysis of these enhanced data streams enables new pattern recognition capabilities and facilitates new applications to be developed inside-the-meter that are unavailable or illogical with on-premise or cloud-based architectures.

Emergence of Inside-the-Meter Analytics

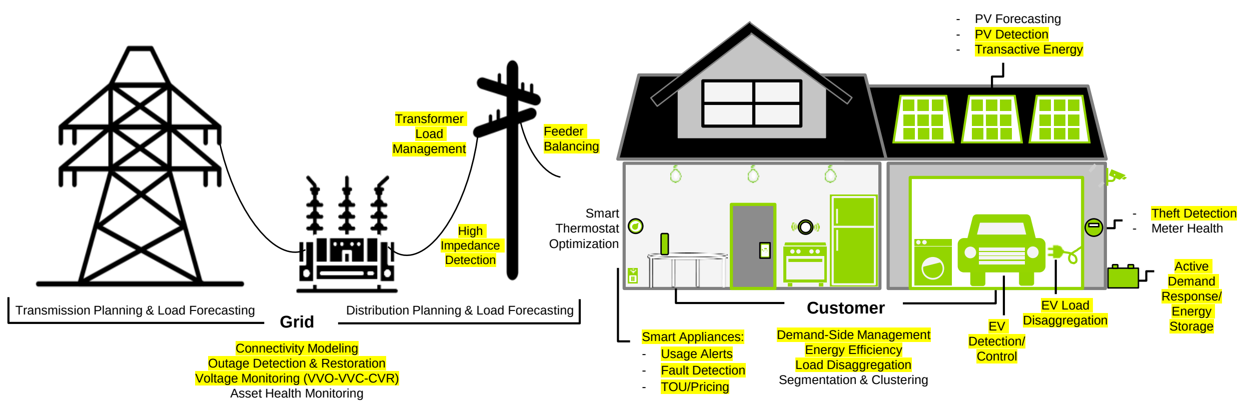
In recent years, the AMI community has been posing a new question: What if AI-enabled analytics capabilities were applied directly to the real-time (often sub-second) data streams being captured inside the device itself? What new sources of value could be delivered to the utility and its customers?

Inside-the-meter analytics architectures were developed by solution providers in response to the availability of new data types (i.e., waveform) and high resolution data capture. Before this there was little to no value to performing analytics at the edge, i.e., inside-the-meter, as the same insights could be generated by performing this analysis in the back office.

Where use cases demand real-time intelligence, such as notifying a customer that they have activated an appliance or EV during a higher priced time interval or sending real-time notifications regarding detected faults and anomalies, the logical solution is to tap into the AI on the meter itself. Doing otherwise would be suboptimal as the cost of moving real-time data and the latency of doing so would likely outweigh the value of these use cases.

Applying AI and ML algorithms to data as it occurs on-the-meter, at the local level, can facilitate a wide range of enhanced use cases. Figure 4 highlights the breadth of applications now enabled or enhanced by inside-the-meter architectures and demonstrates the maturity of use case development as it relates within the larger smart meter analytics ecosystem.

Figure 4. Inside-the-Meter Intelligence Applications



(Sources: Guidehouse Insights)

New Use Cases Emerging

This section discusses the primary applications used to deliver inside-the-meter intelligence to support customer experience, DR, network monitoring, and DER integration.

Customer Experience

Smart meters have proved valuable tools for utilities in engaging with their customers. Many utilities already offer their customers daily or monthly energy usage information and insights regarding their bill. Yet, the majority of these applications have centered upon static reporting and descriptive insights providing customers with limited information. Embedding of AI-powered algorithms into next-generation smart meters enables new capabilities around pattern recognition, real-time usage tracking, and proactive notifications, increasing the value proposition behind several customer-oriented applications, like the following:

- **TOU/peak alerts:** Disaggregation algorithms ingest enhanced smart meter data to detect EV charging or active appliance(s) during peak pricing periods and offer prescriptive energy savings notifications to the customer.
- **Excess usage identification:** Disaggregation algorithms ingest enhanced smart meter data to detect appliance(s) with excess usage, and proactive notifications are sent to the customer. Utilities can use this information for targeted web marketing programs or digital marketplace strategies.
- **Fault detection:** Enhanced smart meter data is used for the detection of broken neutral and poor ground conditions on the customer side of the transformer, improving customer safety and preventing appliance damage.

There is substantial overlap between customer experience, DR, and DER integration applications given the common focus on BTM assets; this creates opportunities for multi-pronged benefit creation across the organization. For example, Grid4C developed inside-the-meter applications that blend DR events with DER detection and proactive customer communications. Using on-meter load disaggregation algorithms powered with enhanced data streams, Grid4C can detect when an EV begins charging and notifies the customer when an event demands real-time insights, such as charging during peak hours. Furthermore, Grid4C can provide customers with predictive insights into the consequences of failing to act in these scenarios, offering a valuable differentiator over purely descriptive analyses.

DR

Until the last decade, utilities and market operators relied primarily on one-way, proprietary communications and control systems from vendors to enable residential DR programs. As the scale of DR programs increased over the past decade, their operational reliability has become more critical and the choice of enabling software and communications protocols has greatly expanded.

The ability for inside-the-meter intelligence to support DR and flexibility services is perhaps the most intriguing for utilities given the immediate value proposition. Inside-the-meter architectures can inflate the value of DR resources through real-time analysis and localized decision-making. Many of the enabling or enhancing capabilities behind DR optimization, such as load disaggregation, enhanced data streams, and low latency, also apply to inside-the-meter analytics. To capture the full value of DR resources and associated use cases, the logical solution is to tap into AI-enabled applications on-the-meter.

- **Active DR:** Peer-to-peer communications among metering device groupings enable active control of DR loads and generation based on reduction target parameters.
- **Transformer monitoring:** Peer-to-peer communications among metering devices operate in conjunction with high resolution connectivity data to enable active control of DR loads and generation based on safe operating limits.

Utilities are searching for dynamic ways to optimize the use of their DR resources. Itron is one company working to provide such an avenue through the development of several DR-oriented applications on its Distributed Intelligence platform. For example, its Active Transformer Load Management application allows for continuous, bidirectional load monitoring across distribution transformer fleets. Using location-based, peer-to-peer metering capabilities, this on-meter application enables active resource control to deliver safety- and data-driven monitoring strategies.

Network Monitoring

This broad set of monitoring applications encompasses asset- and network-oriented use cases. This category of analytics is generally mission-critical and utilities historically implemented it on-premise—yet there has been a steady uptick in cloud-based offerings and a gradual erosion of traditional control and culture barriers. This trend now extends to localized analytics with the embedding of several grid-based applications inside-the-meter.

- **Outage detection and restoration:** Peer-to-peer communications among metering devices operate in conjunction with high resolution connectivity data and outage communications networks to optimize outage detection and reporting. The power restoration process uses similar applications, leveraging peer-to-peer communications and high resolution connectivity data to avoid transformer overload in the safe restoration of power.
- **Voltage monitoring:** High resolution voltage data is monitored in conjunction with configurable alarms to support Volt/VAR optimization (VVO), Volt/VAR control (VVC), conservation voltage reduction (CVR), and enable higher levels of network visibility.
- **High impedance detection:** Enhanced smart meter data enables the detection of high impedance connections within the distribution network. This information provides inherent safety benefits and can be used for proactive maintenance.
- **Feeder phase balancing:** Enhanced smart meter data is used in conjunction with near real-time connectivity information to enable phase load balancing.

With the development of AI-based connectivity modeling algorithms, new location-based (spatial) analytics can deliver near real-time visibility of network connectivity across meters, transformers, and feeders, based on smart meter data. For example, Itron's Location Awareness application provides the connectivity information and electrical location for every smart meter on the network; this information supports a number of additional DI applications, including outage detection and feeder phase balancing.

DER Integration

Over the next decade, the integration of DER is one of the most pressing concerns for network utilities. Real-time control and visibility across millions of devices will only be possible through real-time automation powered by AI and ML. This requires far more than traditional DER forecasting solutions and demands AI-driven techniques for detection, disaggregation, and optimization of DER. Recent innovation has trended toward revenue analytics and transactive energy (TE):

- **EV detection:** Disaggregation algorithms ingest enhanced smart meter data to detect EV ownership at customer premises. Utilities can use this information for usage reporting and targeted web marketing.
- **DER detection**: Disaggregation algorithms ingest high resolution smart meter data to enable detection of unregistered or incorrectly installed customer-owned DER assets.
- **Local markets:** Peer-to-peer communications among metering devices operate in conjunction with high resolution connectivity data to facilitate local power pools. This enables DER asset owners to negotiate real-time purchases with meters at consumer locations with controllable loads.

DER vendors are focused on how they can participate in this changing market. While the proliferation of DERMS has been top-of-mind for the past few years, the simultaneous development of standalone applications for DER integration offers utilities with lower cost, flexible alternatives to enterprise systems. For example, Grid4C offers several cloud-based applications for DER detection, disaggregation, and forecasting. Under its partnership with Itron, the company has been embedding some of these applications inside-the-meter to enable localized DER analytics.

Balancing Cost and Value

Inside-the-meter architectures offer utilities new options regarding where, when, and how they analyze smart meter data. Customers can now choose the right architecture for each specific use case: balancing bandwidth, latency, reliability, and other factors with costs.

Ultimately, much of this discussion revolves around complex trade-offs. Utilities must carefully consider relative trade-offs around meter capabilities, communications constraints, insight types, and value-added integrations in the selection of vendor and analytics architectures:

- **Meter-level:** Although advancements in metering technologies have led to increased computing power and memory embedded within smart meters, these capabilities are not unlimited. Inside-the-meter architectures are complementary rather than catchall in terms of application support, and must be balanced against analytics sandbox constraints (e.g., performance, size).
- **Communications-level:** Field area networks introduce bandwidth and latency constraints that limit the efficacy of hosted and cloud analytics insights. This must be balanced with home area network constraints that may arise from inside-the-meter analytics such as privacy and data access.
- **Insights-level:** The value of real-time insights varies significantly based on the inside-the-meter application at hand. For example, detection and notification of EV charging during peak hours holds a lot more value than detection and notification of a potential AC malfunction. Whereas the EV example has a small value window, insights related to AC performance may still provide value with a 1-day delay.
- **Integrations-level:** Outside of peer-to-peer meter communications, inside-the-meter architectures are extremely limited in the ability to integrate additional sources of data. Hosted analytics and cloud computing enable much higher levels of systems integration. For example,

utilities may opt for traditional analytics architectures for network monitoring applications that benefit from strong OT integrations (e.g., ADMS).

Utilities must recognize and balance these trade-offs in determining their analytics strategies. Vendors are then tasked with developing creative solutions and flexible offerings for utilities so that these trade-offs and constraints become easier to digest.

Big Bets on Inside-the-Meter Intelligence

As the next frontier of smart metering comes into focus, leading smart meter manufacturers are promoting next-generation devices with enhanced communications, data capture, and computing power. These embedded capabilities have been a constant source of product evolution since the dawn of AMI. This newest generation of smart meters provides a viable solution to the data resolution and communications issues that have inhibited adoption of inside-the-meter analytics to date.

There is a lot of discussion within the industry as to the future of inside-the-meter analytics. While certain meter manufacturers have opted for the status quo, due to perceptions on market maturity or other factors, countless others have pivoted aspects of their business to support inside-the-meter techniques.

Next-generation smart meters, such as Riva CENTRON and Revelo, feature high performance communications capabilities and device-based computing power that enable real-time analysis of high resolution data (1-second or better).

At the forefront of this transformation are two smart meter manufacturers, Itron and Landis+Gyr. These companies were early movers in the development of enabling technologies and have continued to innovate in their quest for market leadership.

Itron has been developing its portfolio of inside-the-meter applications for nearly a decade. In October 2014, Itron released Riva, its open distributed computing platform. Now branded Distributed Intelligence, this platform supports applications for outage detection and analysis, theft detection, transformer load management, location awareness, renewables integration, DR, and detection of unsafe grid conditions. More than two million Itron Riva Distributed Intelligence meters have been deployed.

One key element of Itron's Distributed Intelligence platform is the addition of smart meter analytics capabilities operating at the grid edge. In 2020, Itron partnered with several vendors specializing in AMI-enabled analytics. These companies will develop local agents (applications running on Itron equipment) that will disaggregate and analyze enhanced data streams, and make these analytics available in near real-time to produce the benefits described previously.

One example of this is the work Itron has done with Grid4C, a company with deep experience in the area of AI-powered utility analytics. Focused on AI-powered disaggregation and predictive analytics, Grid4C employs non-intrusive load monitoring techniques to deliver enhanced insights without the need for additional hardware. The company is embedding its GridEdgeAI software within Itron's Riva equipment to help customers monitor appliance-level usage and issue real-time, proactive notifications.

Landis+Gyr is also making inroads in the space as part of its Revelo line of smart meters. Combining edge computing and waveform data collection technologies, Landis+Gyr's next-generation meters enable real-time pattern recognition of energy delivery, including fault identification and safety-based use cases.

The company has worked specifically with Utilidata and Sense to confirm Revelo has the data sampling, edge computation, and networking needed to support the wide range of use cases Figure 4 highlights.

Mirroring Itron's production Distributed Intelligence platform, Landis+Gyr's Gridstream Connect Apps creates an open application ecosystem for third-party developers. This allows utilities to download a variety of software applications directly onto the smart meter.

Innovative analytics providers are attracting a broad network of metering partners with a focus on inside-the-meter intelligence.

The facilitation of a vibrant and diverse ecosystem of analytics partners is critical to enabling continuous innovation in an open standards market. This is evidenced by the ongoing surge in partnership announcements and nascent product developments aimed at inside-the-meter intelligence. Yet, the majority of these engagements are still early-stage with multiyear roadmaps. Companies vying for access in this increasingly competitive market should reflect upon the success of the small pool of vendors facilitating inside-the-meter intelligence.

Grid4C has been outperforming nearly all of its competitors in the temporal race to capitalize on and actually deliver inside-the-meter intelligence this calendar year. Building on over two years of collaboration across the AMI ecosystem, Grid4C recently completed its applications on Itron's DI platform and will make its AI-powered load disaggregation and prediction algorithms available to Itron customers in the second half of 2021.

There is a growing number of analytics providers operating across the continuum of inside-the-meter development, such as:

- **Utilidata:** The software company partnered with Itron in 2018 to embed its AdaptiVolt voltage optimization software within Itron meters; this led to the first third-party application launched on Itron's Distributed Intelligence platform. In 2019, the company partnered with Landis+Gyr and is working to deploy energy optimization software within Revelo meters; this will allow for grid visualization (using waveform analysis), dynamic feeder monitoring (using peer-to-peer communications), and real-time grid fault detection.
- **Sense:** The company is working with Landis+Gyr to embed its high resolution processing software application into Revelo meters; this follows Landis+Gyr's purchase of a small equity stake in the company in January 2019. Sense has historically relied upon intrusive methods for load disaggregation via its home energy monitors. Under the Landis+Gyr partnership, however, Sense is expected to offer non-intrusive load disaggregation without the need for additional hardware.

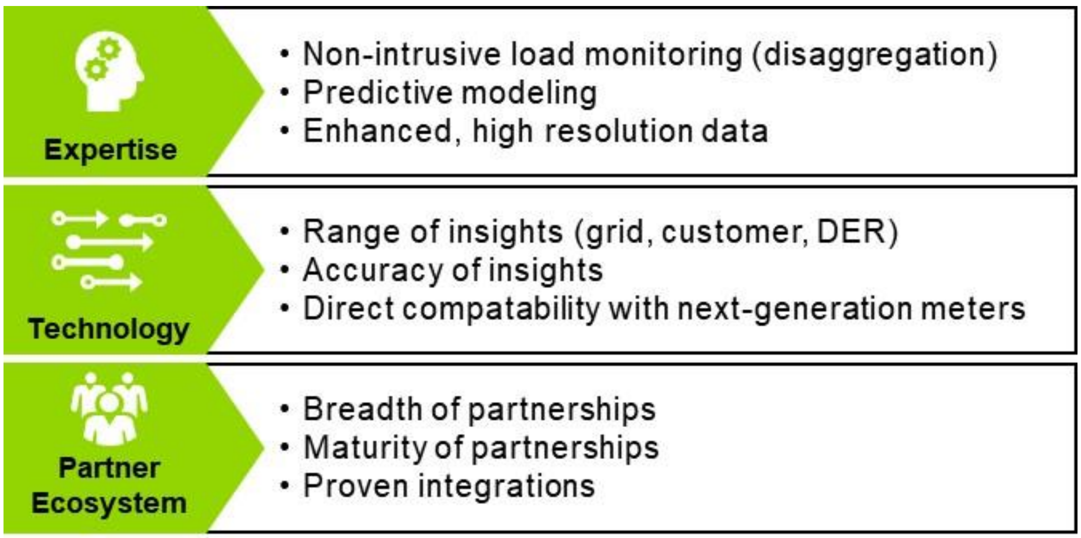
Utilities across the US are already incorporating requests for inside-the-meter load disaggregation capabilities within their RFPs.

This growing collection of strategic engagements is helping stimulate broader levels of vendor participation and utility demand for localized analytics. And although providers remain somewhat fragmented in their approaches to load disaggregation, the market has witnessed a gradual and logical shift away from intrusive, hardware-dependent techniques in favor of more cost-effective, scalable, non-intrusive methods.

Additional hardware costs associated with intrusive methods can become burdensome for many utilities. In the case of Sense, home energy monitors are priced around $300 per unit (without volume discounts); this is approximately three times the average cost of a smart meter in the US. When scaled across a mid- to large-sized utility, the CAPEX implications and trade-offs become significant.

This section highlighted several leading practices and key differentiators that solution providers use to grow their position in the market. Figure 5 aggregates a number of these differentiators and provides a checklist for utilities to consider when comparing analytics providers. For utilities struggling to select the right analytics partner for deploying inside-the-meter-intelligence, there are several areas where vendors are successfully differentiating, across algorithms, delivery models, expertise, partner ecosystem, or otherwise, to compete in an increasingly crowded environment.

Figure 5. Inside-the-Meter Analytics Vendor Checklist



(Sources: Guidehouse Insights)

With the complexity of the information provided, and the broad nature of these solutions, having an open and vibrant ecosystem of partners and solutions providers drives innovation and creates more opportunity for value creation.

The nascency of localized architectures places a premium on solutions providers who demonstrate their expertise in working with enhanced data streams, as well as predictive algorithms and non-intrusive techniques for load disaggregation.

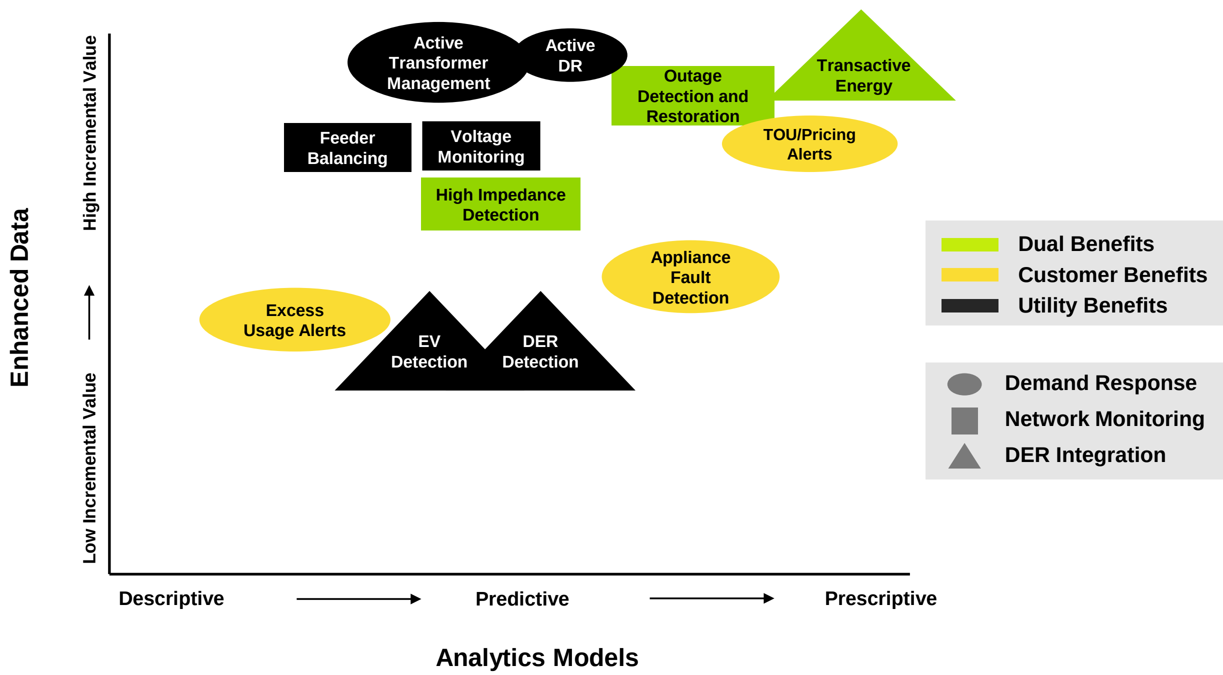
Finally, market competitiveness has emphasized the value of technological prowess when evaluating the field of analytics providers. It is no longer cutting-edge to simply provide non-intrusive load disaggregation; some utilities have conducted accuracy tests between different disaggregation providers as part of their vendor assessment. Similarly, strong expertise in only one or two domains may prove less valuable than holistic providers that can deliver value across the business.

While this checklist is framed specifically around inside-the-meter intelligence, much of this could also be applied to on-premise or cloud architectures. Regardless, the selection of analytics architectures can (and should) use the same body of underlying algorithms and AI-enabled insights.

Optimizing the Business Case

Utilities are searching for dynamic ways to create value from their smart meter deployments. The previous section highlighted the growing ecosystem of enhanced use cases enabled by inside-the-meter analytics. Yet there remains a knowledge gap within the industry around the level of value creation generated by these localized architectures. Figure 6 illustrates the incremental value that inside-the-meter intelligence can bring across the spectrum of utility touchpoints and analytics models.

Figure 6. Value of Enhanced Data for Inside-the-Meter Applications



(Sources: Guidehouse Insights)

While enhanced data streams make only a subset of these localized applications possible (e.g., active DR, feeder phase balancing), others can still deliver benefits using interval smart meter data, such as excess usage alerts and DER detection. This explains the variance in incremental application value that Figure 6 features. However, this incremental value can grow significantly when pairing together two or more applications, such as providing real-time TOU and pricing alerts based on DER detection algorithms.

One example of high incremental value creation is with TE, one of the holy grails of localized analytics. Although utilities are still ill-prepared today to support transactive services, investments in inside-the-meter intelligence are setting the stage for future platform development. According to the Itron and

Zpryme survey, only 4% of utilities are extremely prepared to support TE platforms while nearly 70% are classified as somewhat prepared or unprepared.[2]

While TE remains a largely futuristic capability, the range of DR, network monitoring, and DER use cases that have already been enhanced through the use of inside-the-meter intelligence illustrates why this market is poised for success. From optimizing the grid through higher levels of situational awareness to more effectively engaging with their customers, many of the macrotrends utilities have chased for years now come a bit easier with the development of inside-the-meter intelligence.

Conclusion

This white paper discussed several groundbreaking shifts within the smart meter analytics market over the past decade, culminating in the development of inside-the-meter intelligence. Some of the key market and technology takeaways to consider include:

- Advanced smart meter technologies are now capable of high resolution data capture across energy, voltage, current, and waveform. The increase in granularity and data types enables enhanced pattern recognition and real-time insight generation unavailable with hosted or cloud-based analytics.
- Innovative analytics providers have developed more powerful algorithms (e.g., disaggregation, location) and predictive models that can be embedded within next-generation smart meters to take advantage of enhanced data streams and enable localized processing and decision-making.
- Inside-the-meter architectures will complement, rather than define, the future of the smart meter analytics.
- Utilities must carefully consider relative trade-offs around meter capabilities, communications constraints, insight types, and value-added integrations in the selection of vendor and analytics architectures.
- The adoption of inside-the-meter architectures is still relatively nascent. While interest is growing rapidly, awareness is still needed regarding the value propositions for utilities and customers alike. As the next-generation of smart meters are rolled out, the total available market for inside-the-meter applications grows. As leading practices and business cases are established, the adoption of these innovative architecture will follow.

Utilities should evaluate the ability of their existing smart meter deployments to address the problems of tomorrow. While legacy technologies may support a myriad of use cases seen today, emerging pressures of data management, customer experience, DER integration, and more are forcing utilities and vendors to explore new paradigms, such as inside-the-meter intelligence, that provide the next piece of the smart meter analytics puzzle.

[2] Itron and Zpryme, "Leveraging Distributed Intelligence in an Evolving Energy Landscape," Itron, https://www.itron.com/-/media/solutions/what-we-enable/distributed-intelligence/2020_zpryme_infographic_static.pdf.

Acronym and Abbreviation List

ADMS .... Advanced Distribution Management System

AI .... Artificial Intelligence

AMI .... Advanced Metering Infrastructure

APM .... Asset Performance Management

BTM .... Behind-the-Meter

CAGR .... Compound Annual Growth Rate

CVR .... Conservation Voltage Reduction

DER .... Distributed Energy Resource

DR .... Demand Response

DSM .... Demand Side Management

EE .... Energy Efficiency

GIS .... Geographic Information System

MDMS .... Meter Data Management System

ML .... Machine Learning

OMS .... Outage Management System

SCADA .... Supervisory, Control, and Data Acquisition

TE .... Transactive Energy

TOU .... Time-of-Use

VVC .... Volt-Var Control

VVO .... Volt-Var Optimization

Table of Contents

Scope of Study

Guidehouse Insights prepared this white paper, commissioned by Grid4C, to explore how innovative applications of advanced analytics and AI are helping utilities maximize the value of their AMI investments. It provides an overview of smart meter analytics and discusses the evolution of more sophisticated architectures operating at the grid edge, helping provide more timely, relevant, and actionable insights for customers and grid operators.

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