SMART METERS: DESIGNING A KEY PART OF THE SMART GRID ECOSYSTEM

INSIGHTS, TRENDS AND DESIGN CONSIDERATIONS

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A Smart Choice for Sustainability

Achieving greater sustainability in general requires many changes big and small - from changing the energy sources we traditionally rely on to changing consumer behavior. Technology, specifically smart technology enabled by the Internet of Things (IoT), plays a big role. As a global technology leader with experience across multiple industries, TE Connectivity (TE) understands how to overcome the challenges inherent in IoT applications, especially in devices made for the outdoors or other harsh environments. In this paper, we will examine smart meters - a key part of the smart grid ecosystem - and describe the market growth factors, trends, applications and features to consider.

Many utility (electric, gas and water) companies are already upgrading to an advanced metering infrastructure (AMI) system of connected meters, communications networks, and data - management systems that enables real-time two-way communication between the utility company and the end users' meters to help make operations and billing more precise and efficient, identify and react to problems quickly, and collect deeper insights for better decision-making and long-term planning.

Why Smart Meters?

As IoT applications across industries provide actionable data that can improve efficiencies and lives, utility companies and residents understand that traditional meters may have run their course. Mechanical meters commonly require in-person readings by service personnel and can be prone to malfunctions that can result in incorrect usage information and service calls. Service technicians and meter readers often encounter loose dogs or other obstacles that can make it difficult to get an accurate reading or service the meter properly. Traditional metering systems also slow down responses to power outages, with on-site or transformer problems sometimes taking several hours to identify and repair, especially as utility systems have become more complex.

Smart meters are an essential part of today's smart grid. The smart grid is more than just power generation and distribution; it's an ecosystem of IoT connected technologies and communication networks that allow for two-way communications transmitting data that can be analyzed to assess grid stability, prevent and automatically report outages, monitor advanced digital readouts that can give consumers better information, and more. The smart grid is part of the IoT framework that helps monitor and manage major parts of the ecosystem - such as traffic, lighting, and road conditions - often enabling early detection of problems resulting from power surges, extreme weather, natural disasters and system or component breakdowns.

As populations keep growing and energy demands increase, smart grids are designed to keep costs low for consumers and save resources and costs for distributors. Data from the smart grid can enable more efficient solutions and greater visibility into the network and usage data. Smart grid technology is one of the most sustainable solutions available in the face of rising fuel costs, concerns about environmental impact and climate change, and a rise in natural disasters such as hurricanes and other extreme weather events.

Smart meters can play a key role in this smart grid infrastructure and present a growth market globally that is predicted to grow from $24.53 billion in 2018 to $44.18 billion by 2026.[i] Replacing traditional meters with new, cellular-connected smart meters can lets utilities reduce meter-reading costs, save resources, maximize uptime and offer customers greater service.

Global Market Projections for Smart Meters

The smart meter market saw shipments of approximately 131.23 million units of smart meters globally in 2019 and is estimated to reach 188.12 million units by 2025.[ii] The world's collective drive to combat climate change is boosting most countries' efforts - and supporting many government policies - to adopt smart meters as an essential building block of the smart grid. In the U.K., for instance, the campaign for a Smarter Britain explained the smart meter's essential role as part of U.K.'s commitment to the Paris agreement saying they are a critical part of creating smart energy grids, which will enable the U.K. to transition to a lower carbon future. Claire Perry, Minister of State for Energy and Clean Growth from 2017 to 2019, said:

"A smart energy system will deliver cheaper and cleaner energy for consumers, create high value jobs and help us meet our climate change commitments. Our action plan outlines that a smarter, more flexible energy system could bring benefits to consumers, the energy industry and wider economy worth up to £40 billion over the next few decades. Smart meters are a key enabler to achieving these benefits and have the potential to entirely change the way we interact with our energy system."[iii]

Currently, Europe is leadings the second wave of smart metering with their previous goal of 80% penetration for energy meters by 2020 driving deployments in the past five years. China, Japan and Korea are currently the hotspots in the Asia-Pacific, with emerging economies in APAC becoming key growth markets. In China, the state grid corporation has deployed 476 million energy meters and smart gas metering is gaining momentum due to the expansion of the Chinese natural gas market. Japan is investing heavily in deploying smart electric meters to keep energy prices affordable and to increase safety around their energy supply, particularly in response to the Fukushima Daiichi disaster in 2011.

India, Indonesia, Malaysia, Philippines, Singapore and Thailand expect to see increased adoption of smart meters as well. In February 2020, India's state-owned Energy Efficiency Services Limited (EESL) completed installation of around 1 million smart meters across India through the Government of India's Smart Meter National Programme, with a goal of installing 250 million more over the next few years.[iv]

In Australia and New Zealand, penetration is high in few cities, but low in both countries overall. A strategic alliance between major vendors in the market and communication technology providers is expected to further drive smart electric meter growth. In Africa, Nigeria and South Africa are the most active in smart meter deployment, while in the Middle East the major deployments are happening in countries such as UAE, Saudi Arabia and Qatar.

In North America, most tier 1 utility operations in the U.S. and Canada have deployed smart meters over the past decade. In the U.S. 88% of installations are residential, but only 6 of 50 states have a penetration rate of over 80%. Differences in smart meter penetration rates are often driven by state legislation and regulation, as some states require that regulators approve utilities' cost recovery mechanisms for metering projects. As an interesting side note, almost half of all U.S. electricity consumer accounts now have smart meters, but most consumers do not realize they have the ability to access more detailed data—29% of households didn't even know they had a smart meter.

In Canada, 82% of meters installed are classified as smart meters. Many provinces have installed smart meters and are investing in research labs focused on smart grids and related technologies. Latin America is seeing some increases in adoption but lags overall. The largest ongoing deployments across Latin and South America are in Mexico and Brazil.

Overall, residential meters are the biggest application category, with electric meters being the biggest product category.

Benefits of Electric, Gas and Water Smart Meters

Cost Savings

By monitoring usage in real time, smart metering can detect leaks in utilities both at the residential level and in pipelines. According to PennEnergy, pipeline operators lose approximately $10 billion per year due to pipeline leaks and fuel theft.[v] With advanced smart meters, companies can detect irregularities in flow and immediately react to prevent theft and leaks. For consumers, smart meters can help identify devices and appliances that consume a high amount of energy, motivating them to either change their consumption behavior or buy more energy-efficient devices.

Predictive Analytics

Real-time data from smart meters can also enable forecasts and predictive models to be built for more accurate demand program planning and predictive maintenance. Data can also be used to capture customer insights, influence customer behavior, and develop new rate plans and services for customers. Back-end systems that process and analyze usage data can allow for deeper insights into how resources are used. Utilities can benefit from data analytics that enable better strategic decision-making for long-term planning and future investments. This data can also be highly useful for emergency response planning and risk assessments.

Safety and Comfort

Energy suppliers can use smart meter data to balance the load on the system and can provide better safety and stability. They have insight into meter-related problems, outage information, quality information and more, helping them isolate potential issues often before they become major problems. Utilities can also use the data to identify and track outages to allow for quicker response times, which can be especially important during extreme weather events and emergencies. Smart meters can also be a valuable part of the smart grid during droughts where consumers are first asked to conserve water (which they can now better monitor on their own) and, if the drought worsens, utilities may be able to restrict usage through the smart meter and smart grid infrastructure. A combination of weather data and water usage data can also be used to predict and even prevent a worsening drought.

Smarter and Cleaner Energy Possibilities

Many consumers already have smart thermostats in their home that let them heat and cool their home in a more efficient manner, automatically adjusting their usage for when they are at work, school or on vacation. But no data from that appliance was going to the utility company. Smart meters bring that data to utility providers so they can make decisions based on the peaks and lows - and points in between - of home energy consumption. The smart grid is mainly about using IoT applications to make these sorts of decisions across all facets of the grid. Using the data from smart meters and from the smart grid, energy companies can make better decisions in terms of where clean energy investments may offer the more immediate or greater return on investment.

Reduced Waste

People who use smart meters in their homes typically make significant changes in their energy consumption behaviors, bringing down energy use and emissions. Real-time data generated by smart meters helps identify problems earlier, such as water or gas leaks, making them easier to find and fix. Less of our natural resources are wasted, and the meters save time on-site for repair crews as they often spend less time diagnosing and searching for the leak. Timers and infrastructure modules within the smart grid can help regulate usage and reduce waste as well. In addition, smart meter data can provide real-time information to track potential theft or loss of resources.

Transparency

More accurate, real-time data can allow for more transparency between utilities and customers and between utilities and regulators. With data on demand and no monthly meter reader visit or drive-by necessary, billing can be more precise, with the ability to show consumption targeted to the day or hour. Consumers can be given access to their data through an app or utility website that can let them see their own usage patterns and adjust their behavior.

Obstacles to Adoption

While there are many important benefits to smart metering, there still could remain significant hurdles to overcome.

Heavy Upfront Costs

Implementing smart meters in a power or water distribution system typically involves several billion dollars of investment for deployment and maintenance of the network. The return on investment may not be seen until several years down the road due to the high implementation costs. This is why supportive policies and incentives for utilities to digitize can be so important. Utilities are looking for smart metering features that would help boost monetization.

Connecting to Legacy Equipment

Whether retrofitting smart metering devices onto legacy equipment or replacing the meters entirely, there are still other pieces of equipment along the way that we may connect with. Lack of proper infrastructure for synchronizing new technology with the existing/legacy equipment can slow or interrupt the implementation of smart metering.

Network Integration

Though several devices are commonly integrated with the smart meter system, they can be used to their fullest extent often only when all devices in the distribution and metering network are included in the same communication network. The sheer number of residences that can connect on an electric, gas or water grid further complicates this integration.

Geography

Deployment of a two-way communication network in some areas might be more difficult due to the landscape, like in mountainous or rural regions, for example.

Data Transfer & Storage

Integration of devices for modulation, demodulation and additional memory for storing data logs could increase overall deployment costs.

Data Privacy & Security

Normally, anytime data and signals are transmitted via a network, potential privacy and security issues can exist. The key for manufacturers can be to mitigate these as much as possible in design, focusing on signal integrity, reliable communication protocols, etc. Additionally, utilities can bear much of the responsibility for maintenance of and access to their communication networks, as well as ensuring public trust by being transparent about the system and their efforts.

A Look at Smart Metering Communications Infrastructure and Technologies

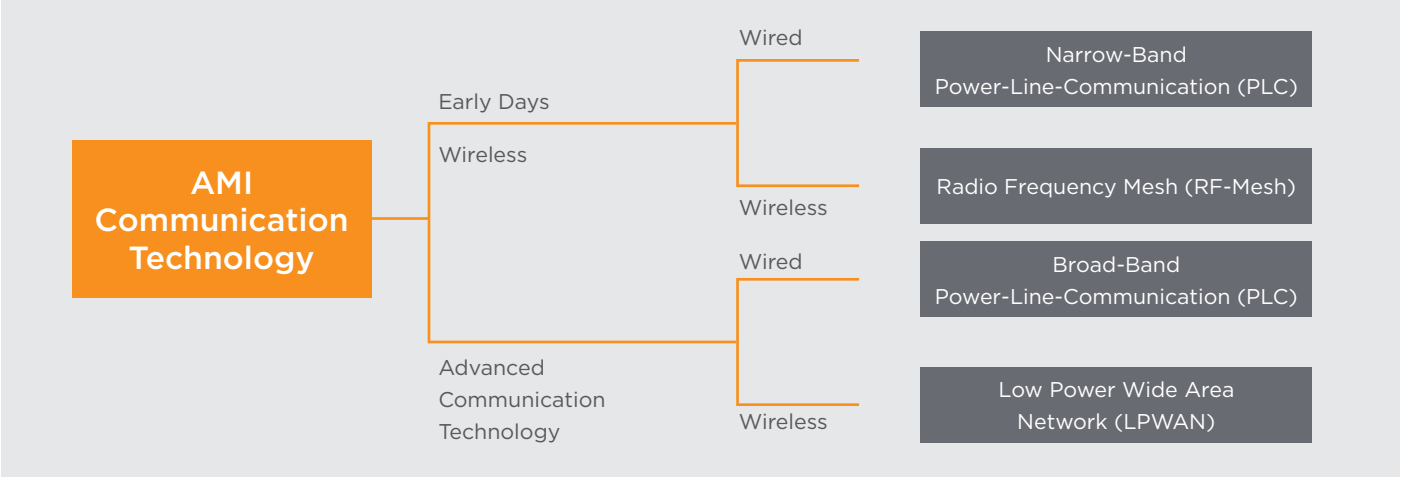
Advanced Metering Infrastructure (AMI) vs. Automatic Meter Reading (AMR)

AMI	AMR
• Integrated system of meters, communication networks and data management systems • Can enables two-way communication between meter endpoints and utilities • Automatically can transmits data directly to the utility at predetermined intervals - no walk-by or drive-by needed	• One-way communication technology with utility personnel needed to collect usage and status data from meters • Walk-by or drive-by reading system with a data receiver in proximity to the meter • Data is stored on a local collection device (usually a laptop) then uploaded to the utility cloud data center later

Two-way communication capability between the utility system and the metering endpoints is a differentiator between AMI and AMR, and due to this and other operational advantages, AMI is likely to lead in the market. AMR may be lower in operational costs with no significant IT resources needed, but it can be cumbersome with personnel required to drive or walk by each customer's residence to obtain accurate usage information.

AMI can provides the information often necessary to help improve energy efficiency, detect leaks and malfunctions, and help utilities manage costs and customer service more effectively. However, it is important that both the network and the communications module in each meter be as low cost as possible.

Networks and Technologies for AMI



The early days of AMI saw narrow-band power-line-communication (PLC) and RF-mesh as the primary communication technologies driving the adoption of AMI and smart meters. As communication technology has advanced, newer technologies such as broadband PLC and low-power wide-area networks (LPWAN) have become more the trend. As you will see below, different technologies may be preferred in different regions, so it's important to understand your market before you design.

Power-Line-Communication (PLC)

PLC can be a cost-effective communication method in which the electric utility uses their own power lines to connect the meters to a concentrator. The concentrator is then connected to the utility's cloud data center with 3G, 4G, or fiber-optic backhaul. PLC returns data useful in analyzing grid performance. Drawbacks of this technology can include the potential for network interference as noise and harmonics on the power line may affect performance and distort communications. Attenuation on some frequencies due to random switching of electrical devices on a power distribution network can lead to changes in power parameters.

Because water meters and gas meters often do not have power lines coming into the meter, PLC is normally not an option for those utilities unless mixing PLC with a second technology, radio frequency.

Radio-Frequency (RF) Mesh

RF mesh is a wireless mesh networking technology in which meters and other devices route data via nearby devices, creating a "mesh" of network coverage. Mesh networks enable end devices to communicate to the collector through multiple hops as needed. Because each end device can register with the collector via another communication path if the present communication path becomes inoperable, network performance and system reliability are often enhanced.

RF-mesh usually uses unlicensed frequencies and is deployed by the utility as an in-house network. This can be a cost-efficient way to deploy and build a network over greater distances while requiring less transmission power per device. However, because RF mesh uses unlicensed frequencies, signal interference can occur, and this communication network option is mainly suitable for restricted ranges with high concentrations of RF modules. It can also be vulnerable to obstructions such as thick walls or tree clusters.

Low-Power Wide-Area Network (LPWAN)

LPWAN is a wireless telecommunications network that allows long-range communications at a low bit rate among connected objects. The low power, low bit rate and intended use distinguish LPWAN from regular wireless WAN that carries more data using more power. Of the various LPWAN technologies, cellular IoT is now part of the wider LPWAN family.

The latest advancements in LTE (long term evolution) technology can enable cellular IoT to emerge for use with low-power devices like smart meters. As more people demanded low-power connectivity to connect their devices while freely moving around, cellular IoT became a preferred route. When used with smart meters, costs are often significantly reduced, and reliable nationwide coverage is possible due to the existing infrastructure built by mobile operators.

Narrowband IoT (NB-IoT), in particular, is a promising fit for AMI systems—it can provide the flexibility utilities seek, scalability for future needs and a solid return on investment in the long run. LTE-M (with enhanced machine-type communications) will probably be the most suitable alternative for smart electricity metering, while NB-IoT can help cover the needs for smart gas and smart water metering.

Even though most of today's cellular IoT networks for smart metering run on 2G, 3G and 4G, it's worth mentioning 5G and what that means for the future. 5G is expected to support over 1,000 more devices per meter than 4G.[vi] 5G can enable better performance, greater connectivity for more sensors and functions and faster power reconnection after outages. Meters are often underground or in difficult to access locations, so the longer battery life and stronger signal propagation 5G can enable helps reduce cost of maintenance and downtime. In addition, because 5G uses shorter wavelengths, design engineers can use smaller antennas to provide similar precision and control as larger, more expensive units.

Regional Preferences

Which technology the customer chooses often depends on where the device will be used - for example, rural utilities normally have very different communication problems than urban utilities, as do utilities located in mountainous regions or areas ill-served by wireless and internet companies. Many countries are rolling out smart meters in tandem with a consortium of market leaders, which can often determine which type of network they use.

Hybrid PLC/RF solutions seem to be rapidly gaining adoption in regions such as Europe and China and are likely to continue to grow at the expense of stand-alone PLC solutions over the coming years. In China, the adoption of NB-IoT across multiple verticals seems to have started to spread into the country's smart metering segment. In Europe, PLC technologies such as G3-PLC and PRIME account for approximately two-thirds of all smart metering installations, and utilities have started to deploy meters using LTE-M, NB-IoT, or a mix of NB-IoT and LTE-M for smart meter connectivity.

Australia and New Zealand are favoring cellular communications, with New Zealand using the LTE-M network for smart meter connectivity since 2019, in addition to their original RF mesh. In India, isolated procurements of smart meters from single utilities seem to have favored RF mesh networks while EESL has chosen GPRS connectivity, with a preference for NB-IoT communications.

What Design Engineers Need

Whether for electric, gas or water, most outdoor smart meters are either exposed to the elements or underground, presenting several challenges for design engineers. These meters must be durable enough to operate reliably for decades and accurately transmit usage data throughout their lifetime. Sensing, power control and circuit protection components often need to be ruggedized and sealed to withstand harsh outdoor elements. Many components need to be rugged and miniaturized to allow space for advanced functionality. Wireless transmission normally need to be resistant to interference so antennas may need to be customized to fit the application, especially for water meters that may be placed a great distance from the residence and may also be entombed in concrete underground.

OEMs should consider using solutions that allow implementation of the same hardware footprint in every market they serve, which can help lower development costs and accelerate time to market.

Design Challenges and Solutions

Weather & Power Surges – Circuit Protection

Weather isn't the only element that can damage components. Electric smart meters are subject to power surges from the grid - due to sudden damage to a transformer or power lines or from lightning during a storm - and electrical transients resulting from inductive load switching or capacitor bank switching. To protect the input power circuitry, designers typically choose metal oxide varistors (MOVs) with voltage ratings high enough to withstand the AC line voltage. Designers can incorporate a thermally protected metal-oxide varistor (TMOV) to protect against brief over-voltages and open-circuit the varistor in case of sustained overvoltage and overheating.

USB Type-C connectors with IPX8 waterproof ratings can support several different protocols and can transfer data up to 10 Gbps. They can be paired with USB Type-C cables for maximum protection in weather-exposed environments. TE's USB Type-C connectors can enable quick, reliable mating and help eliminate EMI leakage through an added protective feature on the back of the receptacle shell.

An electrical switch typically includes an actuator, a moving contact, terminals, and a case or housing. TE switches are cost-effective, reliable, high-performance solutions designed to withstand extreme shock, vibration, temperature, and altitude.

The materials used in the composition of a resistor perform a critical role in enabling performance reliability and stability, particularly for high-voltage, high-power, high stability/accuracy, or high-current applications.

Power Surges, Energy Efficiency and Battery Lifetime – Power Control

Power consumption and control often are key factors in smart metering due to battery life requirements, sustainability goals or requirements, and costs. Normally, the aim is to enable low power consumption (energy efficiency reducing carbon footprint and extending battery life), reduce savings while improving reliability, and increase efficiency by monitoring and controlling electrical performance. Designers can help optimize energy consumption by implementing trip relays to prevent damage when the current deviates from the desired set trip limit. TE's Crompton Instruments relay portfolio is engineered to address these smart metering needs.

Power control components can be used for load switching and energy pulse-out functions in smart meters. Solid-state relays (SSRs) tend to be preferred over electromechanical relays because of their low switching acoustical noise and extremely long life (due to the contactless system). SSRs can be used in smart meters for power consumption limiting, tariff switching, alarm outputs, custom load output and more. They respond quickly and are highly resistant to vibration, shock, dust, gases, and other contaminants.

Interference – Antennas & Wireless Connectivity

With the proliferation of wireless devices and designers increasingly relying on cellular antennas that offer the critical features needed for IoT success, there is interference due to congestion as more and more devices share frequencies and bands. Devices themselves require multiple radio technologies or multiple antennas in proximity for multiple-input-multiple-output (MIMO) or diversity. The tight integration environments and needs for multiple antennas or technologies can introduce issues. Poor integration or design can cause signal noise that can block service or interrupt transmissions.

Choosing an antenna for a smart device can be challenging because system designs can require more sophisticated planning and a holistic assessment of all connectivity requirements, instead of just "plug and play." In many IoT applications, the antenna solution may need to be customized and designed to operate on a secure network. With smart metering, in particular, antennas often need to work from underground and may be in a device housed within a cement box or heavy-duty casing. Signal performance may need to be applicable to the external components and surroundings of the smart meter. A loss in efficiency due to interference could result if the right antenna is not selected. TE Connectivity's IoT antenna offering can provide platform antennas for integration and custom antenna solutions when required.

Heavy-duty casing on smart meter devices that can be resistant to weather, vandalism and tampering could interfere with signal integrity or connectivity, which means a ruggedized external antenna may be necessary. TE's 5G single-input-single-output (SISO) antenna and puck antenna are designed for IoT and machine-to-machine applications, with a weatherproof low-profile housing that can be fitted on a non-conductive panel. Their radiation patterns, ease of integration and robust mechanics can make them innovative choices when integrated antennas are not an option.

Spring fingers offer a cost-effective solution for antenna feeds, can prevent EMI noise and static, can provide a reliable connection and can enable flexibility in design as they normally only need limited space. In addition, high-speed board-to-board connectors and USB Type-C connectors can offer reliable signal integrity and excellent signal speed, transferring data at up to 10 Gbps data speeds and beyond. One-piece and two-piece board-level shields can be used to isolate board level components and reduce EMI susceptibility and noise often without affecting data transmission speed.

Size and Function – Miniaturization

With more advanced functions designed into electric, water and gas smart meters, miniaturized components with lower profile heights, and small centerline or pitch spacing can allow flexibility in design. Look for miniaturized components that are sealed and/or ruggedized for durability over the long lifetime required by utility meters, including:

- AMP CT, AMP Mini CT, and AMP Micro CT interconnects
- FPC connectors
- USB Type-C connectors
- 0.5mm, 0.6mm, 0.8mm and 1mm free height connectors
- SMA/SSMA and micro coax cables and connectors

Privacy & Security

Smart meters can be vulnerable to cyber-attacks, physical tampering and data privacy breaches. OEMs and utilities normally share responsibility for securing these devices and their data during transmission from device to cloud. Strong communication protocols, authentication-based access, and encryption of data (at rest and during transmission) may be enabled within the design. On the manufacturing side, this may include creating and installing device keys, security certificates and configuration parameters—such as a key configuration manager and factory configurator client APIs—for securing and validating information.

Electronic Power Meters from TE

Multi-function metering systems measure, display and communicate over 100 parameters. Petal-array icons show the percentage of full-scale power of the measured system and the instantaneous power factor (PF) measurement gives clear PF indication. High-definition screen features programmable backlight for high-contrast visibility in low light and direct sunlight applications. The light can be programmed to automatically dim after a set period of time for energy saving.

TE Brings an IoT Connectivity Advantage

As a global industrial technology leader, TE brings IoT connectivity expertise to energy, automotive and industrial transportation, factories, defense, the connected home, healthcare and many other industries. Our engineers often collaborate and share their expertise cross-functionally to better help our customers meet their design and manufacturing needs. We do more than offer sensors, connectors, cables, antennas, relays and more that can bring your ideas to fruition in our connected world, we co-create with you to make sure your designs can consider all aspects of function, connectivity, space and interoperability so you can get it right the first time and get to market faster.

We understand how connectors, sensors and other components can work together and use this knowledge to help you optimize performance and create more connected, more energy efficient smart meter designs that can drive functionality, durability and reliability for your customers. We also keep an eye toward manufacturability, innovating to make our products more durable, higher performing and easier to manufacture in high quantity.

These are just some of the ways TE lives up to its purpose of creating a safer, sustainable, productive and connected future, and help our customers win in their markets.

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i. Smart Meter Market to Derive Growth from the Presence of Several Large Scale Companies Across the World. FORTUNE Business Insights. 2021 Feb 12: https://www.globenewswire.com/news-release/2021/02/12/2174685/0/en/Smart-Meter-Market-to-Derive-Growth-from-the-Presence-of-Several-Large-Scale-Companies-Across-the-World.html

ii. Global Smart Meters Market Outlook to 2025 - Smart Electricity Meters Segment is Expected to Witness the Highest Growth. Research & Markets; 2020 Dec 23: https://www.globenewswire.com/news-release/2020/12/23/2149802/0/en/Global-Smart-Meters-Market-Outlook-to-2025-Smart-Electricity-Meters-Segment-is-Expected-to-Witness-the-Highest-Growth.html

iii. The Campaign for a Smarter Britain substantiation document. Smart Metering Communications Body Limited; p. 0-1.

iv. Global Smart Meters Market Outlook to 2025.

v. Particle. The Internet of Energy (report); p. 5

vi. Maçon-Dauxerre, Emmanuel. How 5G Enables Advanced Metering Infrastructure for Smarter Utilities. Telit; 2019 Nov 7: https://www.telit.com/blog/how-5g-enables-advanced-metering-infrastructure-smarter-utilities/

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