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Hype Cycle for Enabling Power and Energy Electronics, 2020

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Combining the right power and energy technologies will enable and support business models that leverage edge data centers, electric mobility, drone fleets and robotic automation. This research assesses enabling power and energy electronics, and identifies partners and roadmap entry points.

Analysis

What You Need to Know

Enterprise architecture and technology innovation (EATI) leaders implementing digital strategies at the edge are limited by devices that need increasing amounts of onboard energy storage for both range of operations and capabilities. These challenges impact particularly those migrating and integrating field operations, warehouse/manufacturing operations, edge computing and supply chains.

Challenges are being created due to a broadening demand for electric power from new applications that require electronics to be tightly integrated with the target use case. To this end, enabling power and energy technologies have moved beyond the lithium-ion battery roadmap with incremental improvements in energy density. Emerging use cases demand a portfolio of power and energy capabilities blended together. Energy solutions better optimizing power conversion, storage and delivery will enable evolving capabilities. Examples include:

- **Edge data centers:** Smaller, more reliable, less maintenance and lower cost
- **Renewable energy storage:** Higher efficiency, smaller, lower cost and socially responsible
- **Electric transport:** Greater range, faster charging, less maintenance and less downtime
- **Drone fleets:** Greater range, more autonomy, faster and in-field mobile charging
- **Mobile robots:** Smaller, longer life, less maintenance and 24/7 operation
- **Automation:** More compact, more capable, more efficient and lower cost
- **Remote systems:** Hard-to-reach systems operating on solar energy and batteries

EATI leaders must make energy analysis a key milestone for new business models, especially those using drones, mobile robots, electric transport and edge data centers. In doing so, these leaders can leverage this Hype Cycle to:

- **Track, assess and select key technologies,** addressing limitations, pain points and challenges in your organization's development or ecosystem.

- **Track adjacent market innovations** for similar use cases in adjacent markets. Also, learn from challenges, pitfalls and successful case studies supported by the leading vendors of these technologies.
- **Identify technologies for combinatorial innovations** to better design your organization's power and energy solutions.

The Hype Cycle

In advancing an edge strategy, edge devices will demand increased independence from line power, either for disconnected operation or for power backup. Business returns will likely grow as enterprises extend the range and duration of remote operations.

This Hype Cycle covers enabling technologies for conversion, charging and storage of power and energy across industries, verticals and use cases. Having a high-level understanding of the progress of these technologies is important when developing and implementing an edge strategy.

Broadly, the trends that demand improved power delivery and energy storage are:

- **More processing in less space.** Technology trends: edge computing, 5G and artificial intelligence.
- **Increased range for electric mobility.** Technology trends: electric vehicles and transport.
- **Greater physical automation.** Technology trends: mobile/warehouse robots, drone fleets and factory automation.
- **Increased requirements for resilient operation.** Technology trends: on-premises energy generation, storage and improved uninterruptible power supply (UPS).

However, challenges are more unique per use case and context, and for this reason, EATI leaders should ask themselves these questions:

- **Is space and integration a challenge?** Power density is increasing across a range of electronics that will require space for more power and cooling electronics.
- **Are things already getting hot?** Thermal emissions from electronics will impact reliability (maintenance costs), performance of surrounding electronics and required housing space.

- **Is mobility constraining operations?** Energy storage capacity, charging time and charging infrastructure all limit the range of mobile robots, drones, electric vehicles and transport.

- **Can we reduce our carbon footprint?** Consider the life cycle of the energy sources you are selecting. Are there combinatorial approaches to boost energy efficiencies?

- **Where, when and how will energy-related regulation impact our business?** Governments are continually implementing tax and penalties relating to the carbon footprint.

- **Are our costs of batteries increasing?** Be sure to evaluate your total cost of ownership of batteries, including battery component cost, maintenance and downtime.

- **Are our costs of energy increasing?** Cost is a more traditional measure when considering power and energy. Do power and cooling costs materially affect your business returns?

Of the innovations in this Hype Cycle, wideband-gap transistors, which include silicon carbide (SiC) transistors and gallium nitride (GaN)-on-silicon transistors, have been gaining the most ground. These transistors operate at a much higher voltage than silicon devices. Although more expensive (like for like with the incumbent technology — silicon), they offer system-level cost savings. These savings come from halving the size, weight and thermal dissipation, and gaining a small measure of increased efficiency. Adoption is broadening as awareness of the benefits increases; the leading vendors in these spaces are technology champions with multiple-case examples, and these vendors can advise on new and emerging opportunities.

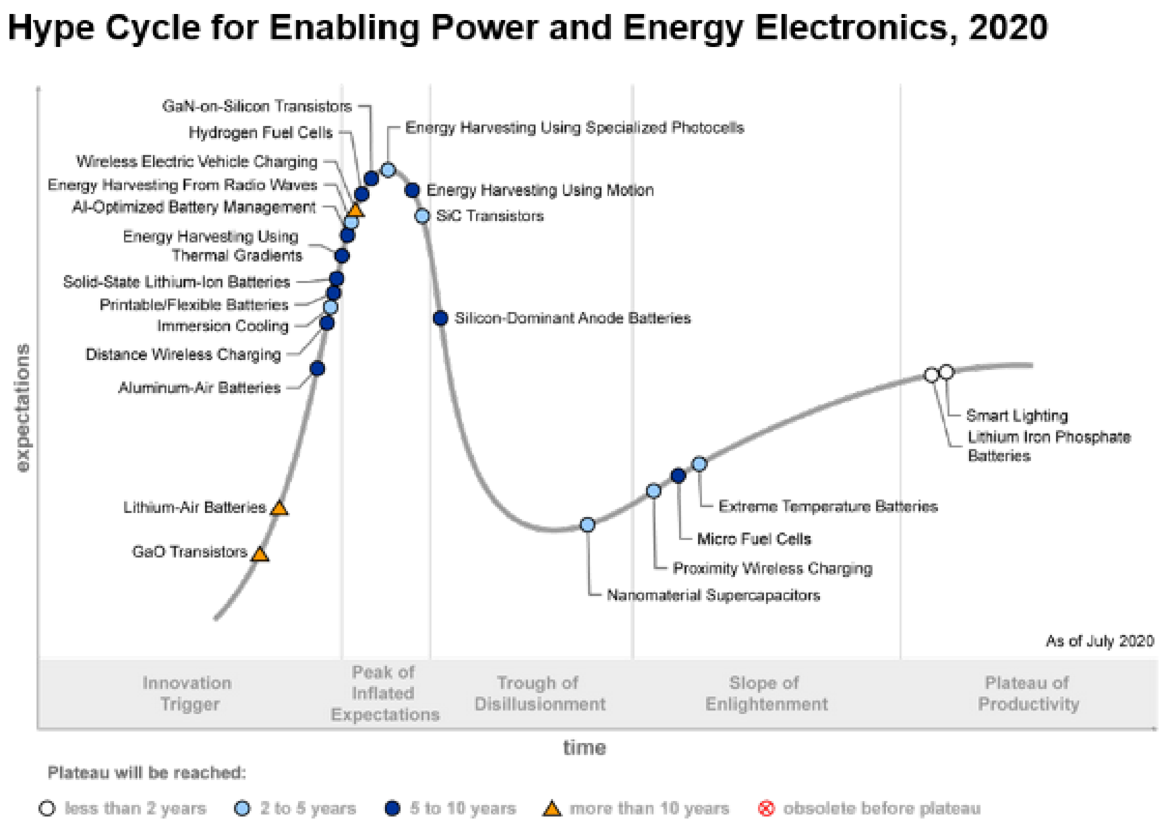
Other notable technologies gaining traction include:

- Solid-state lithium-ion batteries for electric mobility, where most automotive OEMs have product launches targeted for the next two to five years

- Nanomaterial supercapacitors (particularly, graphene), which augment batteries for superior short-term power delivery and capture

- Energy harvesting — particularly, energy harvesting using thermal gradients and energy harvesting using motion — which is enabling energy autonomy in wireless sensor endpoints in industrial Internet of Things (IoT)

Figure 1. Hype Cycle for Enabling Power and Energy Electronics, 2020



Source: Gartner
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The Priority Matrix

Power and energy technologies are notoriously challenging to bring to market while maintaining the full benefits they originally promised — particularly, battery technologies. For this reason, there are few transformational innovations in the Priority Matrix, and they are still a fair distance from reaching productivity. Already, innovations with high and moderate benefits require significant R&D investment, as well and investments in manufacturing and scale — most technologies in this research are in these categories.

A lack of transformational innovations in the power and energy technologies space necessitates that combinatorial benefits form part of the analysis when evaluating these technologies. With a growing pool of emerging power and energy innovations, there is a greater scope for combinatorial approaches to realize significant value. For example, combining supercapacitors and batteries enables a better mix of power and energy optimization, which will provide superior UPS capability. In some cases, usage patterns will have to be reconfigured to get to optimal solution architectures. An example here could be combining fast-charging drone fleets using supercapacitors with high-power density mobile charging platforms (solid-state lithium-ion batteries with GaN-on-silicon transistors for power conversion) integrated into electric delivery trucks. Combined, the technologies here would help with the combination of power density, efficiencies, charge times and costs required to realize such a vision. Use the questions in Hype Cycle section to help prioritize and select technologies for your project.

EATI leaders must reach back in the supply chain and have a dialogue with technology vendors, since this will:

- Better identify the full range of benefits
- Provide opportunity to learn from other use cases
- May steer, in some cases, the development trajectories of new solutions

Providers of foundational technologies are often keen evangelists and are aware of their innovations' potential value in use further down the supply chain. This lesson is a valuable source of information for enterprises looking to capitalize early on new emerging technologies.

Figure 2. Priority Matrix for Enabling Power and Energy Electronics, 2020

Priority Matrix for Enabling Power and Energy Electronics, 2020

benefit	years to mainstream adoption			
	less than two years	two to five years	five to 10 years	more than 10 years
transformational			Aluminum-Air Batteries Hydrogen Fuel Cells	Lithium-Air Batteries
high	Smart Lighting	Extreme Temperature Batteries Nanomaterial Supercapacitors SiC Transistors	AI-Optimized Battery Management Distance Wireless Charging GaN-on-Silicon Transistors Printable/Flexible Batteries Silicon-Dominant Anode Batteries Solid-State Lithium-Ion Batteries	GaO Transistors
moderate	Lithium Iron Phosphate Batteries	Energy Harvesting From Radio Waves Energy Harvesting Using Specialized Photocells Immersion Cooling Proximity Wireless Charging	Energy Harvesting Using Motion Energy Harvesting Using Thermal Gradients Micro Fuel Cells	Wireless Electric Vehicle Charging
low				

As of July 2020

Source: Gartner
ID: 467923

On the Rise

GaO Transistors

Analysis By: George Brocklehurst

Definition: A gallium oxide (GaO) transistor is a type of transistor built from a gallium oxide crystal, which offers a high breakdown voltage, thereby gaining the ability to operate at voltages up to 3kV (a review of the most recent progresses of state-of-art gallium oxide power devices). GaO transistors will significantly improve weight, size and efficiency of electric power trains, power conversion modules and high-power inverters used in renewable energy systems.

Position and Adoption Speed Justification: This technology is still in the laboratory research phase and is likely to be most suitable for lower-frequency high-power applications such as AC/DC conversion — voltage tolerance up to 3kV reported. At this scale, applications will be in larger transport, e.g., trucks, rail, ships and industrial power. Significant time and investment will be required to pull this technology through to production and as a comparison it has taken several decades for silicon carbide to achieve the level of maturity it has today from this point.

A key step has been the move from lateral to vertically constructed transistors, required to achieve the density and voltage capabilities for a compelling value proposition. Germany’s Federal Ministry or Education and Research (BMBF) in 2019 launched a £2M joint project bringing to the table industrial partners for a complete value chain perspective from manufacturing (AIXTRON) to deployment (ABB Power Grids). Meanwhile, FLOSFIA, a Japanese startup, announced results showing 50% improvement in channel resistance, with their “normally-off” transistors, when compared to silicon carbide. The company has a partnership agreement with DENSO and has signed a domestic distribution agreement with Hakuto and Kyoei Sangyo to initially bring a Schottky barrier diode (SBD) to market.

Supply chain progress includes a joint development between AGC and Novel Crystal Technology with aggressive plans for production launch of 650V diodes in 2021. Diode construction is far simpler than transistors but will help establish a supply chain for materials and help pave the way for commercialization of GaO transistors.

Aside from the power handling capabilities, an attraction of GaO is the availability of native substrates (from molten GaO similar to what has enabled silicon manufacture) at relatively low cost — which inhibited gallium nitride development. However, like gallium nitride, the thermal conductivity of GaO is very low, which will have thermal management considerations. Multiple technological, let alone manufacturing, challenges remain to bring GaO transistors to market.

With initial interest from industrial partners and the beginning of a supply chain for materials this innovation profile is moved a step further up the Peak of Inflated Expectations.

User Advice: Gallium oxide transistors are very embryonic, where progress is required through scientific breakthrough. The value proposition is an extension to those wide bandgap technologies (silicon carbide and gallium nitride) further along in the adoption cycle.

- Users with industrial and field operations using larger equipment and vehicles are likely to be earlier adopters. Users in this category should take the time to understand the implications and benefits of extending electrification to higher power use cases.
- Equipment and manufacturing vendors invested in markets where power density is core to long-term success should consider participation in university developments to improve visibility, learning and tracking of this technology.

It is unlikely that GaO will have any significant market presence in the next 10 years.

Business Impact: GaO has significantly greater power density and twice the voltage rating over silicon carbide simplifying high-power electronics, lowering cost and increasing efficiencies. Improvements using GaO for transistors will lead to electronics which provide large efficiency savings for a wide range of use cases from electric vehicles and transport to industrial grid and renewable energy.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: FLOSFIA; NICT; Novel Crystal Technology; Tokyo University of Agriculture and Technology (TUAT); University at Buffalo

Lithium-Air Batteries

Analysis By: George Brocklehurst

Definition: A lithium-air battery is a type of metal-air battery that uses a lithium metal anode, and oxygen from the air as its cathode. This technology has the greatest energy density claims of the metal-air chemistries that, it is hoped, will revolutionize electric mobility.

Position and Adoption Speed Justification: This technology is still only at lab scale and still has fundamental challenges, which are being addressed at the research level. These challenges are mainly around the cell construction and packaging, requiring greater understanding of the electrochemical processes involved, development of new materials to promote desired reactions and minimizing undesired reactions.

Challenges include:

- Initial implementations are open cell, as they require an inflow and outflow of oxygen, and have only been successfully repeated under “synthesized” air conditions.
- Limitations in the flow of air/oxygen limit the efficiency of the reaction, which results in contamination of the cathode and rapid degradation of the cell.
- Charge voltage differs from discharge voltage by 1.2 volts. This reduces charging efficiency to 70% and increases thermal dissipation. Research solutions are emerging to address this.

Multiple research institutions are looking to solve these commercialization problems with annual breakthrough announcements. This year the Daegu Gyeongbuk Institute of Science and Technology (DGIST) reported a lithium-air cell with increased discharge capacity maintaining its performance for the two-month trial. Other research announcements in the last two years include, a cell design lasting for 700 charge/discharge cycles, from University of Illinois and Argonne National Laboratory (2018), the use of 2D materials as anode catalysts from University of Illinois (2018). Improvements in the discharge process were announced by University of Waterloo pushing lithium air closer to 10 times of current lithium technology.

In addition to these challenges, a 2019 report by researchers from Samsung Advanced Institute of Technology, found that lithium air is very far from reaching theoretical performance expectations. Their findings place lithium air closer to 5 times the specific energy and 2 times the energy density of current state of the art.

Moving from lab-scale breakthroughs to some practical implementation will take 10 years. Samsung Electronics' research brings attention to practical implementation while DGIST's research helps to further address the technology's challenges. As such we take another small step along the Hype Cycle.

User Advice: Lithium-air battery is still embryonic, and progress is being made through scientific breakthroughs therefore recommendations are long range:

- Users should take time to understand how a disruptive step change in battery capability would influence your future scenarios. How would a significant increase in drone or mobile robot autonomy, 10 times the electric vehicle range, hours of UPS uptime impact your business model and value proposition. Taking this thought process will help you to understand how these technologies fit into your longer-term strategy.
- Vendors for which battery performance is the core to long-term strategic success should improve their visibility, learning and tracking of this technology. Understanding the longer-term architectural changes required to support lithium-air batteries will be essential to leverage the benefit. Architectural changes will require a parallel commercial R&D effort to converge with the emergence of a lithium-air production solution. The progress in aluminum-air commercialization (Phinergy and India Oil Company), may provide some guidance.

This is a key technology for those involved in electric vehicle, transport and drone development to track.

Business Impact: Lithium-air prototypes have been demonstrated to have five times the power density of lithium ion, and up to 10 times is theoretically possible. A tenfold improvement would bring lithium-air battery close to the power density of gasoline. This level of performance would have a transformational impact on drones and electric vehicles. Success of a closed (sealed) cell or solid electrolyte would have broad transformational impacts across multiple end markets.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Cornell University; PolyPlus Battery; University of Cambridge; University of Dallas

Aluminum-Air Batteries

Analysis By: George Brocklehurst

Definition: An aluminum-air battery is a type of metal-air battery that uses an aluminum metal anode, a liquid (water) electrolyte and oxygen from the air as its anode. These are primary cells; once they are depleted, the aluminum anode must be physically replaced. These anodes can be recycled which will help to offset material costs.

Position and Adoption Speed Justification: Aluminum-air batteries have been prototyped for decades with various demonstrations in electric vehicles. To date, due to cost and primary (nonrechargeable) nature of the technology, they have been restricted to military use cases, such as portable satellite communication packs.

Phinergy, an Israeli startup, has demonstrated solutions powering electric vehicles up to 1,000 km — requiring electrolyte top-ups every ~300 km. In 2020 Indian Oil Company (IOC) acquired a minority stake in Phinergy as they partner to develop, produce and sell aluminum-air batteries at scale — as well as reduce its dependence on Lithium as it migrates its transport network to electric. The technology is particularly suited for rollout in India as it does not need a charging infrastructure. IOC can help to develop the infrastructure for cathode replacement and recycling and install the electrolyte filling capability in their refueling stations. In 2018, Phinergy established a $130 million joint venture with China-based Yunnan Aluminium. Yunnan Aluminium has its own EV venture with a target of producing an initial batch of 2,500 vehicles.

Late 2019, an Indian startup Log 9 Materials, closed a series A round of $3.5 million to commercialize its aluminum-air battery technology targeting an aggressive product launch within 2021. They will leverage graphene to achieve 5x size reductions and efficiency improvements on their current prototype EV also claiming a 1,000 km range. Log 9 Materials' initial target will be stationary solutions including substitute backup generators (5KVA equivalent) for telecommunications infrastructure offering lower total cost of ownership.

In the U.K., Founder Trevor Jackson and his company Métalectrique claim a 1500 mile range and ~$75/kWh battery. The company is attempting to build U.K. government backing.

Challenges for mainstream adoption remain high requiring a major cost down through anode/cathode development and infrastructure for anode recycling. Additionally, there are very few technology vendors supplying aluminum-air batteries. Further announcements come from research, including a breakthrough from UNIST late in 2018 with advances using a “flow” technology that reduces anode cost and side reactions that are costly to reverse in recycling as well as increasing peak power capability.

With larger partners and other potential vendors joining the ecosystem, this technology moves further up the Peak of Inflated Expectations.

User Advice: Aluminum-air battery technology is more mature than other metal-air chemistries, but the resultant open-cell construction and inability to recharge pose challenges to adoption. Due to the battery construction, this technology is more applicable to larger cell sizes. The strong driver here is the lure of much-higher energy densities that are applicable for electric vehicles, drones and backup energy sources — particularly valuable in regions with intermittent power. Lead users who can mitigate the trade-offs of implementing this technology must proactively collaborate with leading vendors to bring solutions to the market.

Business Impact: Aluminum-air has the highest near-term power density with eight times greater capacity than today’s lithium-ion solutions. This has a fundamental impact on electric vehicle autonomy and, therefore, adoption, extending vehicle range up to 1,000 miles on five minutes charging (claimed by Phinergy). Additionally, the recharge process of replacing electrolyte liquid is far quicker and easier than today’s electric charging stations. The final cost structure and process for replacing anodes will be a deciding factor.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Fuji Pigment; Log 9 Materials; Métalectrique; Phinergy

Distance Wireless Charging

Analysis By: Bill Ray

Definition: Distance wireless charging covers the delivery of electrical power over 30 centimeters or more. This may be accomplished using RF transmissions, light or even ultrasound, emitted by a charging station paired to the endpoint. Received power is generally used to recharge batteries housed within a device.

Position and Adoption Speed Justification: There are several technologies that can demonstrate distance wireless charging, and demonstrable prototypes have been developed by a number of companies. However, moving from prototype to commercial product has proved extremely challenging as efficiency, safety and the lack of standardization have proved to be insurmountable barriers.

Inductive charging systems (proximity charging) only operate over very short distances (less than five centimeters). Power carried over other media varies in efficiency based on the media properties and is generally balanced against other limitations. Laser transmissions, for example, can be quite efficient, but need to be accurately targeted; RF requires less targeting but loses power rapidly.

Humans intersecting the transmission path are, outside highly vertical industrial installations, a significant problem. High-power RF systems may rely on sensors that shut down transmission when the path is blocked, but some regulators (and potential users) are concerned about the reliability of such a mechanism. Despite these risks, the U.S. regulator (the FCC) has approved several RF systems for commercial use. Low-power lasers or ultrasound systems may be sufficiently low power to avoid being a hazard to health.

Given the different charging mechanisms available, it should come as no surprise that few standards exist. Companies are pursuing proprietary (and heavily patented) approaches which are unlikely to offer interoperability in the foreseeable future. However, there are clear use cases that would be benefit from practical distance charging, and therefore we expect the profile will come into mainstream use within 10 years.

User Advice: Distance wireless charging can enable use cases that would be otherwise impossible. The ability to deliver power to a mobile endpoint, or one separated by a medium through which wires cannot be used (such as water or volatile gas), can be critical in creating a new application. Distance wireless charging is certainly applicable in such instances.

Projects should be technology-specific, using designs licensed from an existing vendor. The choice of technology will be dictated by the use case, so interoperability is unlikely to be an issue. In the longer term, specific technologies will come to dominate, with standards emerging in five years or so, and companies interested in being part of the standards process should start considering which technologies interest them most.

Business Impact: There is an obvious desire to focus on smartphone charging, as this is probably the most impressive application for distance wireless charging. The ability to charge a mobile phone while it is still in the user's pocket changes the experience, as a much-smaller battery can be topped up by charges concealed in furniture and vehicles. However, this functionality is some way off.

Early applications will include products used in known locations, such as wireless game controllers, VR headsets or IoT sensors mounted in fixed locations. These products exist within a limited physical space and may already be vertically integrated with consoles or PCs, so can more easily be paired with charging transmitters.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Energous; Ossia; Wi-Charge

Recommended Reading: "Market Trends: Wireless Charging of Mobile Devices Needs Smartphone Makers' Endorsement for Success"

"Emerging Technology Analysis: Wireless Power Charge"

Immersion Cooling

Analysis By: Martin Reynolds

Definition: Immersion cooling is a type of data center server cooling system that immerses server boards in a nonconductive heat transfer liquid, typically built using an immersion container in a dense, closed system. Immersion systems deliver well-above-average cooling efficiency, enabling compute systems to run at relatively high performance and floor space density.

Position and Adoption Speed Justification: Open liquid cooling, in which the cooling fluid is in contact with the server components through spray or immersion, is an established technology in supercomputing and military applications. These solutions, however, are either too small or too large for typical data center applications. Furthermore, in some cases the systems use oil for cooling, an impractical messy solution for most businesses. Newer systems use liquids that do not wet the boards and fall back into the cooling pool, or liquids that evaporate quickly with little environmental impact. These systems eliminate the handling issues associated with liquid cooling and work well within existing data center and office environments. Several companies now offer commercially viable solutions that offer up to 10 times improvement in floor space compute density, offering data center managers more flexibility in server deployments.

The server boards use custom carriers for standard server motherboards, or are custom-designed motherboards. Immersion cooled systems are relatively quiet, as the fluids used are far more efficient at heat transfer than air. Furthermore, these servers eliminate the significant power consumption of system fans. These systems, in some cases, take the form of pods with robotic handling in a closed system, improving manageability and sealing the cooling system from the outside. These systems are viable now, but their high power density and novel configurations require customized space and power designs.

As the energy and power density of microprocessor systems advance, liquid cooling will become increasingly important in data center engineering. Immersion cooling may well become a preferred solution in data center environments constrained by space or power environments because of its high efficiency.

User Advice: Immersion cooled systems are significantly smaller, quieter and more energy efficient than traditional data center racks. Their initial value will most likely come from outside the data center, where they enable higher compute density at higher energy efficiency and lower noise. Although the capital cost of the system is typically higher because of the mechanical and cooling infrastructure involved, there are environments where these systems outperform any alternative.

For example, a business might require that its computing take place in, say, a downtown tower block. In these buildings, there is often a floor power budget that covers both equipment and cooling. An immersion cooling system could easily improve power efficiency by 40%, theoretically enabling 66% more energy for computing within the same power budget. A closed system with robotic board handlers can operate in an otherwise open office with minimal sound baffling.

Another application is in medium-scale edge computing nodes or wireless telecom nodes, where immersion cooling helps the system manage the thermal, spatial and power constraints of a remote server bunker, pole or closet. Shipboard or truck-based mobile data centers also benefit from these space and power efficiencies. Some of these systems originate from the cryptocurrency mining space, with an extremely high GPU density. For certain GPU-centric small-scale supercomputing tasks, these systems represent a practical on-premises solution. Therefore, users operating data center equipment in environments constrained by power, space, or cooling should add immersion cooling systems to their options.

Business Impact: Immersion cooling systems enable enterprises to deploy higher levels of compute capability to strategic locations than is possible with conventional air-cooled racks. Key applications include factory automation; large-scale call center operations; edge data centers; data centers in remote or unattended locations. These systems allow greater business efficiency where latency or unsupervised operation are important parameters.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Asperitas; Green Revolution Cooling (GRC); Immersion Systems; QCooling; Submer Technologies

Recommended Reading: "How to Create a Data Center Cost Model Suitable for Public Cloud Comparison"

Printable/Flexible Batteries

Analysis By: Nick Jones

Definition: Printable/flexible batteries are produced using screen printing or thin-film deposition technologies to create batteries which are thin, often flexible, and can be manufactured in a very wide range of shapes and form factors with the thinnest production models available in 2020 being under 700 microns.

Position and Adoption Speed Justification: The term printable/flexible batteries covers a very wide range of devices with different capacities, sizes and chemistries including both single use and rechargeable units. Form factors include flat sheets, ribbons and wires, though virtually any shape can be manufactured using printing technology. Although products are available now, we expect the technology to evolve significantly with new manufacturing techniques, chemistries and form factors emerging through 2030. In the longer term, academic research in areas such as transparent flexible batteries could enable radical new types of electronic devices.

User Advice: In 2020, most users should focus on applications where reduced weight or flexibility is more important than power capacity, e.g., sensors, smart cards or wearables. In the medium term, printed/printable and flexible batteries will benefit organizations wanting to create products with shapes or properties that wouldn't be possible with conventional rigid batteries or the limited range of "off-the shelf" battery form factors. In the medium to long term, organizations wanting to create novel products should monitor developments in areas such as the integration of printed batteries with 3D printing, This is far less mature than thin-film or screen-printed manufacturing but may eventually enable batteries to be integrated into the physical structure of an object.

Business Impact: In the medium term, printable/flexible batteries will be important in situations that need relatively low power and where the size, shape or rigidity of a conventional battery is inappropriate. Examples include:

- Smart cards with integrated batteries
- Smart labels which integrate displays and electronics
- Flexible sensors, e.g., skin patches
- Batteries which are integrated with smart fabric products
- Wearables needing flexibility, e.g., wrist bands
- Disposable thin batteries, e.g., in smart greeting cards

In the long term, printed batteries will have a lot of synergy with the wider space of printable and flexible electronics and will enable new types of products. For example technologies such as smart paper will demand ultrathin batteries, and transparent batteries combined with transparent displays might enable novel electronic products.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: AdaVolt; Blue Spark Technologies; Enfucell; Jenax

Solid-State Lithium-Ion Batteries

Analysis By: George Brocklehurst

Definition: Solid-state lithium-ion batteries replace the traditional organic solvent electrolyte with a solid one. Moving to a solid-state electrolyte has several advantages, including increased power density, removing unneeded components, such as separators, and removing safety risks in the conventional battery design.

Position and Adoption Speed Justification: Moving to a solid-state electrolyte provides a potential two- to three-times increase in power density, mitigating the fire and explosive hazards seen in traditional lithium-ion cells. Drawbacks of moving to a solid electrolyte include higher electrical resistance limiting efficiency and charge rates as battery sizes are scaled up, typically low temperature performance (although some vendors appear to have solved/mitigated this issue) and side reactions degrading performance with time and charge/discharge cycles.

So far, solid-state lithium-ion batteries have found niche applications requiring smaller batteries, mainly driven by IoT-related trends, e.g., wireless sensor networks, home automation and toy drones. For example, in February this year, Cymbet announced a partnership where its technology would enable disposable data loggers for cold chain logistics monitoring. Low cost and small form-factor battery solutions are now available from Cymbet and Ilika through distribution (with battery die as low cost as $0.2 in volume) and license agreements to self-manufacture.

Within the electric vehicle market several events unfolded in the last 12 months. Dyson killed off plans to launch an electric vehicle in 2021, it is still committed to its solid state battery program but the schedule is less clear. By contrast, China-based OEM, Enovate has announced very aggressive plans to launch an electric sports car in 2021 powered by solid state battery technology from ProLogium. ProLogium, is a startup who closed a $100M series D round in April this year. Toyota and Panasonic target launch of a production EV with a solid state battery in 2023. Volkswagen who previously invested $100M in the solid-state startup QuantumScape has expanded that relationship into a joint venture to develop, manufacture and sell the technology. Solid-state batteries are now on the roadmaps of most OEMs, many with either internal developments of stakes in startup companies pioneering alternative solutions in this area. Post-COVID-19, expectations are five and 10 years to see this technology mature and for any sizable share growth within automotive.

With growing adoption of this technology in smaller form-factors and with growing investments/commitment into larger form-factors from the automotive industry, this profile continues to move toward the Peak of Inflated Expectations.

User Advice: This technology is in production with multiple improvements in the pipeline. Technology leaders in the supply chain are working in parallel with cell development to capture first to market advantages by capitalizing on the improvements of this technology. There are multiple points of engagement to be taken:

- Current solutions provide high energy density and long life ideal for IoT use cases, where five to 10 years' infield use is required. Also, applications requiring repetitive charging cycles will also benefit.
- Larger solutions are coming to market. The significant energy density improvements should motivate OEMs to engage in partnerships now to understand integration and capacity ramp requirements and include in product roadmaps.
- Based on its emerging production status and improvement trajectory, this should be a prominent roadmap technology for any company dependent on batteries e.g., for drones, robots, edge data centers.

Business Impact: The solid-state design has multiple advantages in both performance and safety. From a performance perspective, this technology addresses the conflicting consumer demand for faster charging, while simultaneously wanting longer battery life with two times capacity increase and up to six times faster charging possible. Additionally, a solid electrolyte results in a more stable design leading to longer battery life (approaching 10 years) and the mitigation of the traditional safety issues of cell shorting in liquid-based lithium-ion designs. These advantages have wide-reaching benefits to all battery-based devices — its extended lifetime having particular appeal to electric vehicles and industrial use cases.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: 24M; Cymbet; Fisker; Ilika; Ionic Materials; Panasonic; ProLogium; Quantum Scape; Solid Power; Toyota

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

Energy Harvesting Using Thermal Gradients

Analysis By: George Brocklehurst

Definition: Thermoelectric generators are a solid-state device that generate an electric current when exposed to a thermal gradient. The colder side must be greater than zero-degree Celsius and the greater the thermal difference the higher the current generated.

Position and Adoption Speed Justification: Adoption is slowly growing in industrial IoT, particularly where high temperatures can be found and in hazardous or hard to reach use cases. There are multiple suppliers in production of the thermal generation element, but significantly less in developing a more complete solution which is restricting broader adoption. Everactive, a Gartner Cool Vendor, have developed complete multisensing solutions, announcing this year a partnership with Armstrong International to develop wireless steam trap monitoring. Perpetua develops complete thermal power modules — battery replacement/enhancement — and have been working with industrial partners to reduce battery dependence with case examples from hardware manufacturing to chemical production.

Momentum also continues to grow in connected homes and intelligent buildings in the form of self-powered wireless radiator valves for zone-controlled heating — offering one to two years ROI depending on use case. Otego, a startup, is developing organic solutions to lower costs and broaden adoption by removing dependence on rare materials as an active ingredient.

Wearables remain an area of strong interest. Miniaturized versions of the industrial counterparts are being leveraged, e.g., the PowerWatch series 2 by MATRIX. MATRIX are also collaborating, announced CES 2020, with Medico, a healthcare company based in Japan, to develop a thermally powered smartband called "Mother." Within wearables most of the progress continues to be in research institutions. Over the past two years, more focus has moved to form factors and materials suitable for an array of wearable applications. Multiple integration challenges remain, most potential comes from health and medical use cases.

Growing traction in industrial use cases combined with continued expectations as a power source for wearables moves this technology further up the Peak of Inflated Expectations.

User Advice: TEGs provide an alternative energy source which can help mitigate installation costs and/or battery management costs. The inclusion of a heat sink renders solutions relatively bulky, current size of solutions (10s cm^3), use cases are limited. However, new use cases less sensitive to this and driven by trends in the Internet of Things are increasing opportunities, such as building automation and connected home.

Outside of the existing industrial products, this technology is for lead users willing to engage with transducer vendors to pull through new solutions. Selecting the right partner is critical. In an effort to leverage the greatest temperature difference, best-in-class vendors apply as much effort into the thermal coupling of the TEG element between heat source and heat sink as they do in the TEG's element itself. TEG products are available in production, but return on investment must be understood; Gartner provides frameworks to help with this activity in "Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints."

Business Impact: In the near term, thermal-energy harvesting will improve return on investment for industrial IoT projects, e.g., engine health monitoring and building automation, as well as improving consumer experience in the connected home. Benefits will include first-order cost reductions in installation and operation. When combined with batteries these extra measures can triple the runtime between changing batteries or even (in some industrial wireless sensor deployments) generate enough power for indefinite operation. Second-order benefits include greater reach of sensors to inaccessible areas as well as larger sensor networks improving data quality behind decision making.

In the medium term, as the technology becomes more convenient (e.g., smaller or flexible) and more efficient, application will be found in a broader range of wireless sensor use cases, transitioning further into enterprise and consumer end markets. The value proposition will evolve enabling new value-added services to have more sensors embedded into our everyday lives facilitating immersive and customized experiences.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: EnOcean; Face Companies; II-VI Marlow; Micropelt; otego; Perpetua Power Source Technologies

Recommended Reading: "Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints"

At the Peak

AI-Optimized Battery Management

Analysis By: Pedro Pacheco

Definition: AI-optimized battery management uses AI to improve battery management aspects like charging and discharging. AI optimizes performance based on different parameters — such as driving needs, temperature or durability impact. This AI-based system can be useful for achieving the sweet spot when dealing with opposing performance requirements like, for instance, extending battery life and fast charging.

Position and Adoption Speed Justification: In recent years, especially in the automotive sector, batteries have been called upon to fulfill several stringent requirements, but several technological limitations remain, such as charging time and charge life. For this reason, AI in tandem with cloud, could play an important role in bridging the gap where intrinsic battery design cannot deliver. As cloud enables swarm data collection from several batteries simultaneously, AI delivers a more cost-effective and quicker predictive algorithm optimization. Doing the same optimization work without AI would entail testing and assessing a large number of vehicle and battery parameters, which would render the project unattractive. However, AI optimization models for batteries is still at an early stage, and its effectiveness depends on several variables, like size of the data pool, battery type, usage profile and optimization parameters.

Automotive OEMs and Tier 1 suppliers are developing this technology, but are at an early stage. Bosch claims its “battery in the cloud” technology can improve battery durability up to 20% due to the use of AI. It is currently running a pilot in China with transportation company DiDi and automotive company Human Horizons with the purpose of validating the technology. Meanwhile, the Toyota Research Institute has teamed up with teams from Stanford University and MIT, announcing this year that their patented AI technology can greatly speed up the time for testing and optimally charge batteries for electric cars.

Google’s Android team worked with Alphabet’s DeepMind in 2018 to incorporate AI battery management back into smartphones, with the purpose of extending the duration of a battery charge.

With only some companies working on it and very few standard applications developed, this innovation is pre-peak. With the demands for improved battery performance and pace of AI development, hype is likely to grow quickly.

User Advice: Demands for battery performance improvement are ever-growing. Companies where batteries are on the critical path for mission-critical projects must assess this technology and identify roadmap entry points.

AI is only as good as the quality and availability of data. For these reasons, limit the scope of early initiatives to one or two projects, and shortlist just a few parameters for optimization. For instance, Li-ion battery durability improvement could offer a good starting point.

Business Impact: Batteries play an important role in sectors like transportation and energy, which are imposing stringent and growing demands on battery technology. AI optimization of battery management and its performance can become crucial to cover the gap between major battery technology steps. At the same time, usage of batteries for some purposes like electric vehicles is still in a relatively early stage. For this reason, AI offers a platform that can adapt to diverse usage patterns as they become clearer — like battery durability and charge/discharge cycles.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Sample Vendors: Bosch; Google; Intellegens; Stem

Recommended Reading: "What a CIO Needs to Know About the Rise of Electric Vehicles"

Energy Harvesting From Radio Waves

Analysis By: Bill Ray

Definition: Energy harvesting from radio waves covers the generation of electrical energy from the ambient radio waves already common in the environment, making use of Wi-Fi, cellular and broadcast signals to trickle-feed batteries or capacitors.

Position and Adoption Speed Justification: Improvements in this technology have been slow despite the technique being common in the early days of radio. Recent developments owe more to developments in low-power computing than improvements in harvesting efficiency, though such improvements do increase demand. The amount of power being gathered has increased only marginally, while the amount of work to which that power can be put has increased exponentially. RF harvesting also faces a challenge of the ongoing reduction in broadcast power, as cell density increases and transmission efficiency increases. Beamforming techniques now threaten to further reduce the ambient power available.

Beamforming enables a transmitter to direct the radio signal, reducing the scattered signal on which RF harvesting relies. Such a directed signal reduces the ambient energy available for passive harvesting, making the technology easier to use in systems which do not use beamforming (such as Bluetooth).

RFID systems use a form of energy harvesting, in that the reflected radio signal is created by the transmission from the reader. Some companies, notably Farsens, have built harvesting systems that use the signal from an unmodified RFID reader to power sensors, LEDs, and even a screen.

The last year has seen significant developments from market leaders, with Wiliot gaining investment from various supply-chain companies including Amazon. This investment has enabled the company to take its energy-harvesting SoC from prototype to production and discuss customers in retail and shipping logistics. Therefore, we have moved this profile along the Hype Cycle, and reduced the time to plateau.

User Advice: There are few situations where alternative sources of energy, such as solar, vibrational or thermal, are not able to provide comparative supply. The technology is most useful where a known radio source can be harvested, such as the sensors developed by Farsens and Wiliot (RFID and Bluetooth, respectively). These companies use that known source for interaction and power harvesting, ensuring that a minimum amount of power is available.

Energy harvesting of RF signals is a proven technology but lacks a killer product to demonstrate its utility. Users looking at harvesting ambient RF should certainly consider the long-term impact of changes in the radio landscape to mitigate the risk of the harvested signal disappearing, but where a known radio signal is available the technology is quite practical.

Business Impact: Further improvements in energy efficiency, as well as increased efficiency in harvesting RF, will create the potential for everlasting devices dependent only on the continuing presence of radio transmissions. Such devices will prove useful in hard-to-service areas, where solar panels could become obscured and battery replacement is expensive.

Where sensors need to be wirelessly interrogated then the use of the interrogation signal for both power and communications makes sense. Extremely low-cost sensors could (for example) be placed around a building, or a workspace, to report environmental data when interrogated, consuming no power at all at other times.

In more-general deployments, however, the presence of any particular radio transmission (such as broadcast television or 2G GSM) cannot be guaranteed indefinitely, and improved beamforming will reduce the available power, so energy harvesting of RF has a limited window of opportunity.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Farsens; Nikola Labs; Wiliot

Recommended Reading: “Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints”

“Unlock the Innovation Potential of Future Location-Sensing Technologies”

Wireless Electric Vehicle Charging

Analysis By: Zarko Sumic

Definition: Wireless electric vehicle (EV) charging is based on inductive charging that uses the electromagnetic field (EMF) to transfer energy between two objects. Induction chargers typically use an induction coil to create an alternating EMF from within a charging base station. A second induction coil in the vehicle takes power from the EMF and converts it back into an electrical current to charge the battery. In addition, stationary charging technology can potentially enable dynamic charging for vehicles as they drive down the road.

Position and Adoption Speed Justification: The technology remains in its infancy and can only transfer small amounts of power over very short distances. It is based on an application of magnetic induction, which uses a changing magnetic flux to push electrons and create a current that transfers electricity from an energy source to a battery. The technology, developed at MIT, uses a principle known as strong coupling. Here, the magnetic fields of two properly designed devices with closely matched resonant frequencies can couple into a single, continuous magnetic field to enable the transfer of power from one device to the other efficiently and over a distance range that is useful for real-world applications.

Compared with conventional EV charging, some cost-conscious consumers may still find it less attractive. In addition to higher cost to wireless charging infrastructure EV manufacturers charge an additional fee for wireless charging or offer it as a standard option to the more expensive models. Despite EV market growth and forecasts of much more to come in the next 10 years, early adopters are likely to recharge their EVs at home where there may be less need for wireless charging.

Wireless charging technologies can be divided into three distinct use cases, which map to specific technologies. Stationary charging, which delivers power to a parked vehicle, quasi-dynamic charging, which delivers power to a vehicle temporarily stopped at a traffic signal or rest area, and dynamic charging, which can deliver power to a vehicle in motion. As these use cases differ from the traditional ICE drive train refueling experience, they required change in user experience. The change in user experience, in addition to technology immaturity, is a significant barrier to wireless electric vehicle charging adoption and is responsible for its slow movement over Hype Cycle.

User Advice: Inductive charging carries a far lower risk of electric shock compared with conductive charging, because there are no exposed conductors. The ability to fully enclose the charging connection also makes the approach attractive, where water impermeability is required. Despite different user experience, compare to conventional ICE engine refueling, inductive charging makes charging mobile devices and EVs more convenient. Rather than having to connect a power cable, the unit can be placed on or close to a charging plate, or in the case of dynamic electric vehicle charging (DEVC) drive overcharging path embedded in the road pavement.

One disadvantage of inductive charging is its lower efficiency and increased resistive heating, in comparison with direct contact. Implementations that use lower frequencies or older drive technologies tend to charge more slowly, and generate heat for most portable electronics. Newer approaches, such as one developed at MIT, diminish the transfer losses with ultrathin coils, higher frequencies and optimized drive electronics. Thus, providing chargers and receivers that are compact, more efficient and can be integrated into mobile devices or batteries with minimal change. These technologies provide charging times that are the same as wired approaches, and are rapidly finding their way into mobile devices. The barriers to widespread adoption, such as additional cost both for EV option and charging infrastructure installation, will be difficult to overcome.

If used in conjunction with vehicle-to-grid (V2G) technology, the vehicle battery can supply energy to the grid at periods of peak demand. This requires additional communication between the grid, charging station and vehicle electronics. DEVC (though still in an embryonic phase) can significantly improve the convenience of use for EV and reduced range anxiety, which is one of the main barriers for EV adoption.

Business Impact: The distribution and energy retail domains will have a major impact. The time-coincident charging of many large battery packs could require expensive electric distribution network upgrades. These costs can be mitigated if the charging can be scheduled away from peak electricity demand periods, or during periods when electricity costs are low. The current uses are mostly based on a car driving over a charging mat installed in public or private garages or parking spots. Potential wireless EV charging applications could include creating long strips of inductive charging plates on roads and highways that charge vehicles as they drive over them to enable DEVC. Because there is a small gap between the two coils, inductive charging is one kind of short-distance wireless energy transfer.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: BMW; Evatran (Plugless); Mercedes-Benz; Toshiba; Toyota Motor; WiTricity

Recommended Reading: “Top 10 Trends Driving the Utility Industry in 2020”

“Market Trends: Wireless Charging for Electric Vehicles Creates New Opportunities”

“Business Moment: Home Energy Management and Electric Vehicles Rescue the Power Grid”

Hydrogen Fuel Cells

Analysis By: George Brocklehurst

Definition: A fuel cell is a device that converts chemical potential energy into electrical energy. Hydrogen fuel cells require hydrogen combined with oxygen (air) and produce water, heat and electricity. This technology (when including a hydrogen tank) is an alternate energy source to battery storage.

Position and Adoption Speed Justification: Majority of recent activity has been in transport. With the trucking industry pressure to reduce CO2 emissions reinforced by sharply rising road tax for diesel trucks, it provides motivation to move to greener fuel sources. Fuel cells have greater range and faster refueling than battery power alternatives. There have been a number of announcements around partnerships to develop fuel cell powered trucks including: Daimler Group and Volvo Group’s joint venture valued at $650 million announced April 2020; Nikola and VectraIO announced a merger to accelerate production of its battery-electric and hydrogen fuel cell vehicles; Toyota and Hino Motors announced their partnerships with prototypes to hit the roads this year; China backed Foton Motor Group and pledged a $2.6 billion investment targeting 200,000 “new energy” busses and trucks on the road by 2025. Many of these initiatives target the classic eight-truck segment competing alongside the Tesla Semi. In terms of field deployments, Hyundai will launch the first of their fuel cell powered trucks in Switzerland this year as does VDL in a government funded scheme, H2Share, which begins testing fuel cell trucks in the Netherlands.

There have also been deployments and field trials for fuel cells in public transport — similar value proposition to trucking. China is a significant investor in fuel cell technology launching 800 buses since 2018 with more ramping up to the 2022 Beijing Winter Olympics. Outside of China, recent field deployments include: Trolleybuses switch to fuel cell operation in Riga, Latvia and in the U.K. Optare (subsidiary of Ashok Leyland) launches its “H2” fuel cell double-decker bus.

Outside transport fuel cells has lost momentum. There was some traction in U.S. data centers with the support of government incentives, but this fell away when subsidies stopped. Bloom Energy — a longer running vendor and champion of fuel cell technology — during the COVID-19 crisis has been supplying systems to hospitals to provide electricity to temporary facilities. Earlier in the year Bloom launched its “AlwaysON Microgrids” solution offsetting opex challenges through financing options. These systems offer value where grids are susceptible to extended outages.

User Advice: Hydrogen fuel cell systems have much higher energy densities than battery alternatives — compared to gasoline powered engines and as such are 10 times higher than best in-class battery storage. Other benefits over batteries include fast refueling — same as gasoline — and an energy density which scales near 1:1 with volume. A key premise with fuel cells is that it doesn’t have the polluting by-products of gasoline, however, the source of hydrogen is something to be aware of as often fossil fuels are used in its production.

- Less attractive for small engine replacements: Expensive equipment, lack of fuel infrastructure and much lower well to wheel efficiencies — 20% to 30% compared to 70% to 90% for battery solutions.
- More attractive for large engine replacements: Energy density scales better than battery alternatives whilst having a lower carbon foot print to gasoline. Examples include class eight-heavy trucks (versus battery) and backup power (versus gasoline generators). Backup power solutions require additional efficiency enhancing strategies such as thermal energy harvesting to reach acceptable economics, installations can reportedly achieve 50% to 65% efficiency compared to the coal or nuclear power stations with 33% to 45% conversion efficiency.

In summary, the technology is available and emerging. For companies where transport networks form a significant part of operations, engage with leading vendors in this space creating business cases that consider the trajectory of cost and efficiency improvements. Those businesses able to set out their own fueling infrastructure will be better able to adopt earlier.

Business Impact: Hydrogen fuel cell technology is likely to have the largest impact on the transport industry. Battery adoption and the “well to wheel” efficiencies claimed to date will make it difficult to significantly penetrate the light vehicle market in any short to medium term. Hydrogen is a more attractive source of energy long term, but requires clean and efficient production methods. Commercialization of the technology for transport and backup power will drive investment into greener and more efficient ways of creating hydrogen, which will broaden its application and disruptive opportunity.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Bloom Energy; Daimler Group; Honda; Hyundai; Nikola; Toyota; Volvo Trucks

Recommended Reading: “Technology Innovation and Global Regulations Drive New Interest in Alternative Fuel Trucks”

GaN-on-Silicon Transistors

Analysis By: George Brocklehurst

Definition: Gallium nitride (GaN) is a compound semiconductor whose properties yield high bandwidth and high-voltage transistors. GaN alone has significant manufacturing challenges therefore it needs a substrate. Previously, silicon carbide has been used which is cost prohibitive for many use cases, therefore moving to a low cost silicon substrate has reduced many barriers to adoption.

Position and Adoption Speed Justification: GaN-on-silicon transistor revenues are still relatively small, $45 million compared to a power transistor TAM of $12 billion, but the supply chain and ecosystem is maturing. A growing number of leading semiconductor vendors have GaN products or supporting chips for its implementation. Most recently, ST the leading vendor of silicon carbide transistors, acquired a majority stake in Exagan, a GaN startup, and announced TSMC as its GaN-on-silicon manufacturing partner.

Highest growth adoption is coming from USB-C charge adapters with multiple third-party vendors announcing new solutions 50% smaller and lighter to those using incumbent silicon technology — OEM solutions will follow. Adoption over the next one to two years will be rapid in this segment taking advantage of 100W capable USB-C power delivery adoption.

Adoption in industrial power supplies has been slower to realize in part due to slower new technology adoption rates in these segments. We are seeing broader field implementations and a growing number of case examples across end markets. These examples are proving opex and capex savings as well as new use cases — and business opportunity — enabled by the technology. Growth rate will build over the next three years in these higher value industrial and automotive use cases to become the dominant segment for this technology.

Within RF infrastructure applications, the key partnership (announced Feb 2019) remains MACOM and ST. The driver here is supporting an attractive cost down versus GaN-on-silicon carbide, ST and MACOM expect 10 to 20 times decrease in cost per power amplifier. This comes at a point when 5G is driving significant content increases with broadening adoption of massive MIMO.

We are close but still not quite at the Peak of Inflated Expectations.

User Advice: This technology is applicable for any roadmap where power density is an inhibitor from a few tens of watts to many kilowatts. High value use cases include edge data centers, on-site renewable energy generation and energy storage, electric transport/vehicles, charging of drone fleets, mobile/warehouse robots and industrial/mechanical automation.

- **Existing use-cases (see business impact section):** Prioritize a business case analysis with some urgency. Leverage existing case examples available online or direct from vendors to clarify returns and benefits from implementing the technology.
- **New and emerging use cases:** Reach back in the value chain to the technology vendors to leverage their learning and expertise on what solutions could look like and the likely benefits realized.

Business Impact: GaN on silicon case examples are demonstrating the end-to-end value of this technology:

- **Electric vehicles:** With multiples savings in space, weight and efficiencies as well as cost savings, GaN will have a significant impact on EV adoption. Onboard chargers demonstrating 3x power density improvement support the fast charge roadmap. As high-power versions are introduced GaN will challenge IGBT and SiC for the power train.
- **Data center:** The ability to double the power density of server supplies and halve losses has a significant impact across the data center spectrum. Enablement of edge data centers in new space restricted locations through to 50% utilization improvement and millions of dollars in opex savings in larger data center operations.
- **Renewable energy and microgrids:** The efficiency and space savings afforded by GaN provide material improvement in the ROI of on-premises renewable energy generation and storage. Case examples show 8% round-trip efficiency increases.
- **RF infrastructure:** Cost savings of moving GaN to silicon often an attractive proposition for RF infrastructure at a time when 5G is driving up to 10x content increases in the Remote Radio Head (RRH).
- **Other use cases of note:** Improvements to wireless power transfer for faster and more frictionless charging of drone fleets. Compact yet higher power motor controllers enabling better integration for factory automation.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Dialog Semiconductor; EPC; Exagan; GaN Systems; Infineon Technologies; MACOM (AppliedMicro); Qromis; Texas Instruments; Transphorm

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

Energy Harvesting Using Specialized Photocells

Analysis By: George Brocklehurst

Definition: Nontraditional photocells are a type of photoelectric generator that uses printable or deposited layers. These devices can be flexible, or transparent, or multilayered for multiple wavelengths and therefore higher efficiency. Initially, these devices align with smaller and short-lived energy harvesting applications, but longer term could deliver significantly improved efficiency for solar generation.

Position and Adoption Speed Justification: New thin-film technologies, e.g., dye-sensitized solar cells, perovskite and quantum dot solar cells, are improving low-light level PV conversion and are better at optimizing for specific wavelengths. This offers performance optimization to particular weather climates (i.e., cloudy regions) and for indoor use cases. In addition, lower costs, flexible form factors, printable solutions and in some cases, transparent solutions open up much broader opportunities for integration. Previously a major adoption inhibitor revolved around stability — lifetime; light-induced as well as environmental degradation have largely been resolved. Most recently, 2020, Solliance partners TNO, IMEC and the Eindhoven University of Technology, demonstrated scalable encapsulated perovskite solar modules capable of passing the three key stability tests; light soak, damp-heat and thermal cycling tests.

Perovskite has made significant progress jumping from 14% efficiency in 2014 to 25% in 2019 (lab-scale single cell results). A number of vendors globally (in U.S., China, EU), have or are now developing low cost print-based production processes for Perovskite single cell solutions. There have been multiple announcements in the last year of 16% to 18% efficiency measurements at the cell level from these emerging technology providers. However, losses will be incurred with module integration. Saule Technologies, a Polish startup, has moved a step forward with a prototype production line supplying modules with a consistent 10% efficiency. Saule has now secured a £4.3 Million grant to mass produce flexible modules specifically for IoT applications taking advantage of the materials ability to be tuned to artificial light. Moving toward higher efficiencies, Oxford PV, a U.K.-based startup, has verified (2018) efficiency for its perovskite/Si tandem cells of 28%. Tandem cells are expensive by comparison and more aligned to the traditional solar renewables segment. Oxford PV extended their series D investment from an initial £31M in March to a total of £65M, adding China-based renewable energy company Goldwind and photovoltaic equipment supplier Meyer Burger.

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Low cost and flexible solutions have allowed integration into a handful of wireless keyboards and bags, which can trickle charge an internal battery for integrated phone charging. There has been little uptake in these products. More recently, Building-Integrated PV (BIPV) is creating demand as flexibility and transparency creates many more design opportunities. With decreasing product costs and increasing efficiencies IoT trends will benefit significantly from this technology as light/solar as a power source is one of the more prevalent energy sources for harvesting. Use cases adopting now include Bluetooth beacons and wireless sensors in building automation where power requirements are much lower.

With multiple vendors establishing prototypes and prototype production lines, this technology has hit the Peak of Inflated Expectations. The following year we will begin to see more case examples, especially those attempting to address IoT applications.

User Advice: These technologies provide an alternative energy source for low-power electronics particularly suited for indoor applications. The cost, size and efficiency of these solutions offer greater value to larger-scale networks of wireless sensors where the aggregate cost of battery changes becomes significant. For consumer use cases, this technology is still for lead users willing to engage with technology vendors to pull through new solutions optimized for target use cases. (For analysis, see "Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints.")

Business Impact: In large-scale and low-power indoor wireless sensor networks, such as building automation, these technologies can offer significant savings in operational costs as well as endpoint autonomy. These benefits will justify new sensor networks or larger sensor networks to generate more comprehensive data to help enable better decision making.

Due to the flexible quality of these new technologies, they lend themselves to improved integration in wearables, smart workspaces and consumer equipment. These use-cases require contextualized electronics that integrate seamlessly to reduce end-user friction.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Alta Devices; Fujikura; G24 Power; Oxford PV; Peccell Technologies; Saule Technologies; Sony

Recommended Reading: "Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints"

Energy Harvesting Using Motion

Analysis By: George Brocklehurst

Definition: Motion energy harvesters are small electric generators which convert kinetic energy in motion, e.g., vibrations, into an electric current. This technology needs to be matched to the frequency and magnitude of movement to be harvested.

Position and Adoption Speed Justification: Electromagnetic-based harvesters continue to be the dominant solution. Vendors developing these types of solutions are experts in vibration, which is also a key data source for monitoring an asset in the industrial space, e.g., water pumps, motors, bearing health. As such some vendors have narrowed their focus on specific use-cases and expanded their offering to deliver analysis and actionable insights. Example vendors include 8power who have conducted successful pilots monitoring water pumps within water treatment facilities and Perpetuum who are expanding their presence in rolling stock health monitoring in the rail industry. We expect to see harvesters capable of supporting broader band vibrations including support for variable motors. Given the need for solutions to be optimized against the frequency and level of vibrations, available vendors are offering customization services.

Advances in small-scale energy harvesters, e.g., MEMs and Piezoelectric, have been slow to emerge as this pushes up the frequency of vibration required to induce meaningful levels of electricity, which is contrary to where most mechanical energy is found. In machines this is 60Hz to 120Hz, while human motion is measured in Hz. Wireless/Batteryless light switches, e.g., "Battery-free by EnOcean" and other switches supporting Bluetooth or Zigbee, have been the significant, and growing, opportunity for these harvesters due to the low power required and predictability of the energy generated each time.

As we see little progress from small scale harvesters and growing case examples from larger electromagnetic-based harvesters, this innovation moves over the Peak of Inflated Expectations.

User Advice: Mechanical energy harvesting provides an alternative energy source which can help mitigate installation and/or battery management costs. Due to the current size of solutions — e.g., a cylinder of 65 mm diameter and height and efficiency, use cases are predominantly limited to industrial end markets. Industrial IoT endpoints typically present valuable use cases less sensitive to size where autonomy is valued or wired installation costs are high examples include wireless sensors attached to rotating shafts on machinery generating lots of vibrational energy. Mechanical energy harvesting products are available for adoption, but return on investment must be understood. Vendors, especially those vertically expanding their solution, should be able to help with assessing and realizing new opportunities. Gartner provides frameworks to help with this activity in "Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints."

Business Impact: Mechanical energy harvesting will improve return on investment for industrial IoT projects, e.g., predictive maintenance and automation. Benefits will include first-order cost reductions in installation and operation. Second-order benefits include greater reach of sensors to inaccessible areas as well as larger sensor networks providing increased coverage and resolution improving data quality behind decision making.

In the medium term, as technology becomes more convenient (e.g., smaller or flexible) and more efficient, application will be found in a broader range of wireless sensor use cases, most likely still within industrial and commercial end markets given the size of solutions versus the mechanical energy required.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: 8power; EnOcean; Midé Technology; Perpetuum; ReVibe Energy; Silent Sensors; Smart Material; Tohoku Steel; Wireless Sensor Solutions

Recommended Reading: "Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints"

SiC Transistors

Analysis By: George Brocklehurst

Definition: Silicon carbide (SiC) is a compound (silicon and carbon) semiconductor and compared with silicon has 10 times higher breakdown voltage, higher power handling capability and faster high-voltage switching capability. SiC transistors that benefit from these properties are relatively new, brought to production in the last decade. These properties lend SiC transistors to high-voltage power conversion use cases.

Position and Adoption Speed Justification: Manufacturability has been the main adoption inhibitor, as expensive raw materials, a limited supply chain and low yield have kept cost high. Volume is the key to yield improvements and cost reductions to make this technology more accessible to broader markets.

Significant volume ramp up occurred through 2018 and 2019 as Tesla adopted STMicroelectronics' Silicon Carbide transistors in its Model 3 electric power train. This is the fastest growth business for Silicon Carbide transistors and represents one-third of 2019 revenue in this segment. We are seeing growing design wins with global automotive OEMs for the power train and onboard chargers (which will challenge GaN). Volkswagen and Cree announced their partnership in 2019 and Delphi announced a $2.7 billion order for power train inverters using Cree's transistors. This market is set to grow 45% compound annual growth rate (CAGR) through 2024.

Industrial power modules form the largest end market for SiC with a growing number of cases ranging from 1kW to over 100kW. Growth and adoption rates range from 10 to 20% CAGR through 2024. Faster growth will come from electric vehicle charging infrastructure and electric transport.

Meanwhile, capacity is a growing concern to meet electric vehicle demand. In 2019, Cree announced its intention to invest $1 billion to establish a new 8-inch SiC foundry. STMicroelectronics, market share leader in SiC transistors, announced its acquisition of SiC wafer manufacturer Norstel, extended its Cree supply agreement to $500 million and established a $120 million supply agreement with SiCrystal, a ROHM Group company.

In 2019, SiC transistor revenue edged past 5% share of the DC power transistor market. With ramping volumes, a supply chain set for scale and multiple announced design wins this innovation moves closer to plateau.

User Advice: Multiple established vendors are promoting SiC transistor products; while, early low volumes equate to this being a high-cost technology, volume is ramping. Adoption is more compelling where there is a high value placed on compactness and efficiency of power electronics rates in kW.

The costs of implementing SiC transistors should not be compared stand-alone to incumbent technologies; they should be evaluated at the system level, where aspects such as a simplified thermal/switching design are taken into account. Particularly in industrial applications implications for capex vs. opex must be carefully considered and evaluated against risk appetite for change.

SiC transistors are not a drop in replacement to insulated-gate bipolar transistors (IGBTs), as the electrical interface requires different drive conditions and the benefit is realized only when the surrounding circuitry is optimized. As identified in the adoption section, EVs, industrial power supplies, transportation, EV charging infrastructure and renewables are markets where SiC has a strong value proposition. Competing technologies, such as GaN on silicon, which is increasing in power capability, should also be considered and evaluated.

Business Impact: SiC transistors has significant impacts on key use cases summarized below:

- **Electric vehicles (EV):** Efficiency improvements result in lower battery costs and more miles per charge. ST has cited a 20% improvement in miles per charge as well as reduced battery costs.
- **EV charging infrastructure:** SiC transistors enable greater power delivery and, therefore, opportunity to halve or better the charging time achieved by today's silicon solutions.
- **Renewable energy:** SiC transistors halve power loss directly lowering cost of energy generation. In addition, Infineon Technologies quotes a 20% reduction in system costs due to thermal design simplifications.
- **Industrial Power Supplies:** Up to 10% efficiency improvements in kW power supplies provide for compelling opex improvements — lower runtime and maintenance.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Sample Vendors: Cree; Fuji Electric; Infineon Technologies; Microchip Technology; Mitsubishi Electric; ON Semiconductor; ROHM; STMicroelectronics

Recommended Reading: "Market Trends: New Semiconductors Enable Compact and Energy-Efficient Power Converters"

"Why All the Investor Buzz Around Silicon Carbide and Gallium Nitride?"

Sliding Into the Trough

Silicon-Dominant Anode Batteries

Analysis By: George Brocklehurst

Definition: This innovation replaces the anode of a lithium-ion battery with silicon. Silicon has a theoretical 10 times greater capacity for storing lithium ions over today's graphite anodes. This profile focusses on silicon-dominated anodes as opposed to anodes infused with silicon oxide to boost capacity as used by Tesla.

Position and Adoption Speed Justification: Claims from companies and research teams range from three to 10 times greater energy storage density than current lithium-ion batteries — the former is more realistic in the short term. The technology's main challenge is that a fully charged silicon anode swells by over 100%, which in turn creates lifetime, reliability and mechanical issues.

While large corporations are developing and evaluating this technology — examples Panasonic (supplies Tesla), LG Chem and 3M — it is emerging providers that appear to be making progress in moving toward commercialization. Enovix secured a further investment $45 million to ramp production of its 3D cell architecture, which boosts energy density and cycle life of silicon anode batteries. Another silicon anode startup, Sila Nanotechnologies, also secured $45 million funding and expect to be supplying its first customers within a year. Finally, Enevate, who focuses on electric vehicle charging solutions and work on a technology license model, announced its fourth generation silicon anode technology declaring sufficient maturity to scale to gigafactory scale.

Further improvements include using silicon nanowires to increase twice the specific energy and four to five times the energy density. Initially, this will be high cost and targeting very high value applications. By example, Amprius Technologies has developed such technology partnering with — and recently receiving investment from — Airbus Defense and Space. This will implement the technology for high altitude pseudo satellites and other similar initiatives.

Multiple startups gaining investment moves this innovation along the Hype Cycle. However, timing is critical — versus other battery technologies gaining momentum — for how this technology navigates the trough to get mainstream.

User Advice: This is a near-term-battery technology which with the advances in other solutions — e.g., momentum building in solid state lithium-ion batteries — is at risk of missing its window and prescale will have a premium cost. For companies involved in high-value use cases for battery technology should engage with emerging providers and understand roadmap and production schedules versus other solutions. Adoption costs must be considered carefully. For cost sensitive areas engagement with emerging providers should look to understand cost value trajectories when evaluating roadmap entry points.

Business Impact: While theoretical improvements are large near term examples are closer to 50% improvements weighted against a much higher cost. These performance improvements can still have a very meaningful impact on many use cases, but cost will be a strong inhibitor within the next three years. The ability of this technology to break out of high value use cases to have a broader impact will depend on its ability to find momentum and outpace other innovations to scale.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: 3M; Amprius Technologies; Enevate; Enovix; LG Chem; Nexeon; Panasonic; PNNL; Sila Nanotechnologies

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

Nanomaterial Supercapacitors

Analysis By: George Brocklehurst

Definition: A nanomaterial supercapacitor is a type of electrical capacitor that stores more energy than current supercapacitor technologies. The nanomaterials enable both greater electrode area, and thinner separators. Nanomaterial supercapacitors can one day approach the energy density of nickel-cadmium rechargeable cells, but can rapidly charge and discharge, making them suitable for many energy bridging applications.

Position and Adoption Speed Justification: A few parties are now leveraging graphene electrodes to significantly increase electrode surface density. The most notable progress has been made by Skeleton Technologies who offers solutions with four times the power density of existing solutions using their proprietary curved graphene. Following an investment of €25M into a new German plant last year the company is manufacturing approximately 1.5 million cells per year. Skeleton Technologies is currently supplying version one of its product in several form factors, including custom designs for specific customers. These are used in applications such as active suspension in cars and intrawarehouse logistics robots. Other use cases have been enabled by supply chain partners working directly with OEMs, including China's CRRC supplying electric trains that can run on super capacitors alone by 30-second top-up charges at each stop.

Other developments pursue a lithium-ion battery replacement by creating hybrid super-capacitors, using both electrochemical and electrostatic energy storage. However, these have been unable to capture the advantages in power and energy density without the trade-offs resulting in a middle ground solution. One startup ZapGo, based in Oxford, is developing a graphene-ion supercapacitor, with higher voltage capability than traditional super capacitors with energy densities approaching lithium-ion. Most recently, 2019, ZapGo announced a joint venture with AS Green Cube Innovation in Norway to implement their technology into EV charging infrastructure by mid-2020.

Skeleton Technologies' progress in establishing volume supply and demonstrated value in an expanding array of use cases moves this technology out of the Trough of Disillusionment.

User Advice: Nanomaterial supercapacitors are in production and should be evaluated for use cases requiring fast energy capture, burst mode power and high-speed charging. This is still an emerging technology with ongoing energy density and capacity improvements that should be tracked to understand when new high value use cases are enabled. Power density is the key advantage over other storage solutions where power bursts are created in either control or capture use cases e.g., in automotive electric turbo versus regenerative breaking. Mainstream solutions are fairly mature, but limited. Those looking for innovation must partner with vendors of emerging high power density solutions in order create truly compelling opportunities. Working with vendors like Skeleton Technologies, who have broad visibility of use cases is recommended to assess value as well as identify opportunities for adoption.

Hybrid supercapacitors are a key technology to track as a battery replacement. It is likely that this will initially enter the market through mobile robots and possibly hybrid vehicles with lower-power electric drive trains.

Business Impact: Nanomaterial supercapacitors offer superior energy efficiency and performance to the electronic functions within which they are implemented, e.g., better supplying peak power requirements while allowing a primary battery to be optimized for energy density. These benefits provide significant value for electric vehicles (seeing implementation in electric buses, e.g., China) by extending range and helping to reduce charge times — both of which are significant barriers to adoption.

Leveraging nanomaterials for smaller supercapacitors offer benefits to end markets influenced by IoT trends, where the energy density of such a capacitor is sufficient to power an endpoint as its primary source. Benefits include a much longer life, lower risk and simpler energy storage solution, significantly reducing life time operational costs for an IoT endpoint network.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Sample Vendors: AVX; Cornell Dubilier Electronics; elna; Eaton; KEMET; NICHICON; Panasonic; Skeleton Technologies; Vishay Intertechnology; ZapGo

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

"Market Trends: IoT Endpoints Will Need New Technologies to Achieve Scale"

"Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints"

Climbing the Slope

Proximity Wireless Charging

Analysis By: Amy Teng

Definition: Proximity wireless charging typically uses two coils that are coupled allowing the transfer of power. This technology is used to charge predominantly personal devices across distances of five centimeter or less.

Position and Adoption Speed Justification: A platform solution is critical for the proximity wireless charging market because it promises interoperability and greater cost-effectiveness of personal devices — which represent a huge market potential.

Wireless Power Consortium (WPC) and AirFuel Alliance are two main organizations fostering standardization for proximity wireless power charging arena. WPC dominates in the mobile device market because of the support of a broad range of consumer electronics and mobile device OEMs; WPC certified products are labeled with a “Qi” logo for easy identification by consumers.

Apple’s full lines of iPhone and AirPods charging cases are Qi-compatible. Google, Huawei and Samsung also included WPC wireless charging into their flagship smartphones and wireless earbuds throughout last year. Currently there are over 250 smartphone models supporting WPC wireless charging.

Acer, HP Inc., and Logitech have introduced desk-based PCs with charging cradles, monitors with charging pads, and keyboard, mouse and headset that are capable of being wirelessly charged. Emerging semiconductor technologies such as gallium nitride (GaN) transistors are being used to push power up coolly and efficiently, enabling more compact and aesthetic design.

The adoption for small devices and smartphones continues, offset by slow adoption where higher power is required. As such this innovation takes only one step forward.

User Advice: IT leaders in enterprises with many mobile device users should evaluate the benefits of proximity wireless power charging, starting from identifying the use cases that can be meaningfully impacted through inclusion of wireless power charging functionality. Be conscious about the power lost during the power transfer process, make sure you maintain a good balance between gaining operational benefits and reducing carbon footprint.

Technology product managers should track emerging technologies that will improve efficiency and charging speed, evaluate proximity wireless power charging to add product values and enhance user experience effectively.

Proximity wireless charging reduces friction of use which is a critical aspect of wearable adoption. Charging without cables, plugs or connectors is good for devices that need to be sealed for waterproofing. Additionally, small battery capacity brings the charging time at a similar level of wired charging; and this makes proximity wireless charging technology more attractive in small devices than smartphones.

Business Impact: In the workplace environment, user demands will be limited, especially in view of future office desks in which docking stations will provide fast data, high-power supply and neat cabling through the emergence of USB Type-C with Thunderbolt. Small wireless power charging will be useful for devices such as a wireless keyboard, mouse and Bluetooth beacons.

In a public environment, proximity wireless charging decently fits in interior designs creating differential experiences in contrast to wired charging through fragile wall USB sockets.

Wireless charging for mobile PCs will be very useful in conference rooms or libraries where desks offer wireless power charging for users who are mostly visitors but with a long occupancy time. Wireless charging can encourage their occupancy and participation without interruption of worrying power drains, and searching for power plugs and cords.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: Apple; MediaTek; Powermat; Renesas Electronics; Samsung; STMicroelectronics; Texas Instruments; WiTricity

Recommended Reading: "Market Trends: Wireless Charging for Electric Vehicles Creates New Opportunities"

"Emerging Technology Analysis: Wireless Power Charge"

Micro Fuel Cells

Analysis By: Jon Erensen

Definition: Micro fuel cells (MFCs) provide an alternative to batteries in mobile devices. They may be small enough for integration inside the device or a little larger for use as external power supplies. Most fuel cells use hydrogen as the base fuel, but MFCs usually operate from a hydrogen-rich liquid such as methanol or butane. MFCs can provide up to 10 times the energy storage capacity of a lithium battery but are not as good at delivering bursts of high power. This makes them more useful for battery charging than for primary power roles.

Position and Adoption Speed Justification: This technology stays in the same position on the Hype Cycle this year as we have not seen a material change in adoption. The only major application for MFCs has been in drones and certain robots because it has a higher power-to-weight ratio than traditional lithium ion batteries, allowing devices to operate for longer periods of time or over longer distances. But there has been little progress in addressing the many challenges associated with MFCs which include the lack of a global fuel supply infrastructure, stability issues and high costs. MFCs that are truly portable and could be incorporated into devices such as smartphones and other compact electronics are still limited to the concept and prototype stages. Fuel cells used as chargers for mobile devices remain stalled, because solutions based on rechargeable lithium ion batteries are less expensive and widely available. The availability of solar-powered chargers is another alternative for users in remote locations.

User Advice: Vendors of equipment such as drones, where the higher power-to-weight ratio is critical, should establish relationships with MFC companies and design MFC solutions into special models for their products. But it is important to understand the limitations of the technology, including distribution challenges and cost.

Emergency responders should consider MFC-based chargers as part of emergency preparations to allow smartphones and other mobile electronics to be used in situations where traditional power supplies will be unavailable for extended periods.

Business Impact: As an alternative power source, MFCs can be attractive and enable longer working times in certain mobile devices and applications.

MFCs have the potential to enable mobile devices with smaller footprints because of their higher power-to-weight ratio.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Aquafairy; Hitachi; Horizon Fuel Cell Technologies; Intelligent Energy; LG Electronics; NEC; SFC Energy; Sony

Recommended Reading: "Government Policies Will Drive Further Electric and Plug-In Hybrid Vehicle Market Growth in China"

"Forecast Overview: Industrial Electronics and Semiconductors, Worldwide, 2017 Update"

"Utility CIOs Must Get Ready for the Digital Grid"

Extreme Temperature Batteries

Analysis By: Nick Jones

Definition: Extreme temperature batteries are designed to power equipment operating at high or low temperatures, where conventional battery technologies and designs are inappropriate. Current products can operate at temperatures from -100C to more than 125C. Future developments are likely to extend operating temperature ranges still further.

Position and Adoption Speed Justification: A wide range of battery chemistries and construction techniques has resulted in batteries that can tolerate and operate at extreme temperatures. Chemistries such as lithium thionyl chloride are already available in a wide range of capacities and form factors, although they're more expensive than traditional lithium or alkali battery technologies. More technologies will emerge as the domain matures, because battery technology is an active research area, and academics are developing new designs that likely to have even better performance at extreme temperature ranges — e.g., using solid electrolytes that are unaffected by freezing. We expect new battery technologies to emerge for the next five years or more to further extend operating temperature ranges and performance.

User Advice: Organizations developing electrically powered equipment or Internet of Things (IoT) sensors/endpoints to operate in demanding low-temperature environments should explore those relatively mature (if somewhat expensive) technologies. These batteries can deliver good performance in applications such as cold chain monitoring or outdoor sensing. Similarly, there are products for high-temperature applications in which battery cost is not an issue, such as smart medical equipment that can survive autoclave sterilization. As technologies mature during the next five years, some lower-cost devices, such as sensors, may be able to exploit extreme temperature batteries. However, we don't expect the prices of even mainstream extreme temperature technologies to approach those of consumer battery technologies, which are manufactured in huge volumes.

Business Impact: In a wide range of situations, electrical or electronic equipment must operate at extremes of temperature, and suitable batteries can power motors or sensing and communications equipment. Examples include:

Low temperature:

- Cold chain monitoring
- Outdoor IoT and sensing in cold regions, such as Siberia or the Arctic.
- Deep diving equipment

High temperature:

- Subsurface sensing in oil and gas wells
- Surgical equipment, which must be autoclaved
- Outdoor equipment in hot climates that can exceed 50C
- Batteries situated next to heat-generating electronic components

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: Custom Cells; Excell Battery; Shenzhen Grepow Battery; Tadiran

Entering the Plateau

Lithium Iron Phosphate Batteries

Analysis By: George Brocklehurst

Definition: Lithium iron phosphate (LiFePO4) battery is a type of lithium iron (Li-ion) rechargeable battery. Its characteristics include lower cost, higher output power capability and superior safety when compared broadly to traditional lithium iron storage solutions

Position and Adoption Speed Justification: The speed of adoption of LiFePO4 batteries will vary with specific usage; some power tools already use this technology. Current difficulties in producing identical cells with a high rate of consistency will slow adoption in some cases. This is particularly important for EV batteries (those containing hundreds of cells, for example). If the cells are not closely matched during manufacture, then costly power management electronics must be added.

LiFePO4 batteries are being used in EV, data center and base station applications, in part due to cost advantages despite lower energy density when compared to state of the art lithium iron solutions. The Chinese government are accelerating the growth of local battery vendors for their local EV production, encouraging them to develop LiFePO4 batteries. In February 2016, the Chinese government announced that it would terminate the subsides for electric bus that did not have LiFePO4 batteries. As the result, it became difficult for non-Chinese battery vendors to enjoy the subsidies. A leading example, announced in May 2020, is Tesla's introduction of LiFePO4 in its Model 3 variant for the Chinese market. Given the visibility of the Tesla brand, this may spark additional interest in this technology. In other sectors, 5G is an adoption driver as the need for greater network cell density requires smaller macro cells while concurrently managing higher energy demands. As such, the industry is shifting from lead acid as a backup power source to lithium solutions which have greater energy density. LiFePO4 batteries are a good fit for this use case offering energy density improvements over lead acid while offering lower cost compared to other lithium solutions.

User Advice: This technology offers an alternative for cobalt-based lithium iron solutions for electric mobility and backup power solutions. Particularly, users considering backup power within base stations, edge data centers and UPS upgrades should evaluate LiFePO4 batteries and leverage their higher temperature capabilities.

Business Impact: Possibly the benefit driving a lot of adoption is the lower cost solution of LiFePO4 solutions over higher-end lithium iron solutions — up to 10%. Other significant benefits of LiFePO4 batteries over the more traditional cobalt-based Li-ion batteries are increased power output, faster charging, reduced weight and longer lifetime. The use of more abundant and less toxic materials helps lower production energy costs and end of life handling. These batteries also have superior safety characteristics as they are not prone to thermal runaway and even if punctured will not catch on fire. LiFePO4 batteries also eliminate the concerns of cobalt entering the environment through improper disposal once they have expired.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Mature mainstream

Sample Vendors: Cell-Con; EEMB; Lithium Werks; ReliOn

Smart Lighting

Analysis By: Nick Jones

Definition: Gartner defines smart lighting as a lighting system that is connected to a network and can be monitored and controlled from a centralized system or via the cloud. Advanced smart lighting systems include controls, connectivity, analytics and intelligence. They usually exploit LED technology for energy efficiency.

Position and Adoption Speed Justification: Smart lighting is being rapidly adopted. It is driven by energy savings, which can approach 70%, compared with conventional lighting. Application areas include offices, homes, industrial plants and city street lighting. Lighting may be controlled and connected in several ways, including Power over Ethernet (PoE), and wireless or wired networks. Advanced smart lighting systems integrate with building management systems to optimize illumination and energy consumption using a combination of light management and building controls, such as sun blinds. Modern smart lighting systems that support programmable color can provide features, such as circadian lighting, where subtle color variations are claimed to improve worker well-being.

The sensors used by smart lighting systems can also support other applications, such workspace optimization. Vendors are exploiting opportunities to integrate other features, such as Li-Fi, location tracking, occupancy counting and Bluetooth beacons, into light fittings. Basic smart lighting for energy-saving purposes will advance rapidly through the Hype Cycle, because it's a well-developed technology, although advanced features (e.g., circadian lighting and workspace optimization) will develop more slowly.

User Advice: In indoor situations, CEOs, CFOs, facilities managers and CIOs should explore opportunities for smart lighting to save money and provide safer and more effective working conditions. Buyers should look for opportunities to integrate smart lighting with building management and integrated workplace management systems to achieve additional benefits. Organizations responsible for retrofitting smart lighting into existing buildings or streets that wish to minimize capital expenditures (capex) should explore lighting-as-a-service models. In such cases, contractors replace and operate lighting hardware, which is funded by a long-term subscription or a percentage of electricity savings.

City planners should explore smart street lighting to save energy and to improve citizen safety and quality of life using contextual dynamic controls. Smart street lighting systems can also provide the physical and networking infrastructure to support other smart city sensors and initiatives.

Sophisticated smart light fittings may include additional features, such as Bluetooth beacons, which can help support initiatives including indoor navigation when used in conjunction with a mobile app. Users should be cautious before adopting smart lighting with integrated data transmission technologies, such as Li-Fi, which we expect to achieve limited market traction through 2023.

Organizations should also explore how analytics can be applied to the data generated by smart lighting systems — e.g., to better understand and optimize office space usage or pedestrian/traffic behavior in streets.

Business Impact: The benefits of smart lighting include energy savings, improved working conditions, better space utilization and reduced operational expenditure (opex).

Smart lighting can save more than 70% of the lighting energy bill, compared with incandescent lighting. Secondary benefits include improved productivity from superior or safer working conditions, cost savings from optimizing office space utilization and improved levels of citizen services. However, we do not expect Li-Fi integrated with smart lighting to be widely adopted, because the business value is limited.

Indoor and outdoor smart lighting also provides operational savings in areas such as inspection and maintenance — e.g., because smart lights can test themselves so emergency lighting doesn't need expensive regular manual inspections. In specific situations, such as street lighting, there may be additional benefits. These include the ability to increase illumination in the event of incidents to aid first responders, and savings from reducing the cost of secondary functions, such as cleaning lights. (Small increases in illumination are less expensive than manual cleaning.)

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: Acuity Brands; American Industrial Partners (Current); Digital Lumens; Enlighted; OSRAM; Panasonic; Signify; Telensa; Tridonic

Recommended Reading: "Evolve Your Smart Building Solutions in the IoT Area"

"Turning Smart Cities Into Intelligent Urban Ecosystems"

"Emerging Technology Analysis: Approach Li-Fi With Caution Because Adoption Will Be Slow"

Appendixes

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 1: Hype Cycle Phases

(Enlarged table in Appendix)

Phase ↓	Definition ↓
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant press and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the technology is pushed to its limits. The only enterprises making money are conference organizers and magazine publishers.
Trough of Disillusionment	Because the technology does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the technology's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the technology are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the technology to reach the Plateau of Productivity.

Source: Gartner (July 2020)

Table 2: Benefit Ratings

Benefit Rating ↓	Definition ↓
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2020)

Table 3: Maturity Levels

(Enlarged table in Appendix)

Maturity Level ↓	Status ↓	Products/Vendors ↓
Embryonic	▪ In labs	▪ None
Emerging	▪ Commercialization by vendors ▪ Pilots and deployments by industry leaders	▪ First generation ▪ High price ▪ Much customization
Adolescent	▪ Maturing technology capabilities and process understanding ▪ Uptake beyond early adopters	▪ Second generation ▪ Less customization
Early mainstream	▪ Proven technology ▪ Vendors, technology and adoption rapidly evolving	▪ Third generation ▪ More out-of-box methodologies
Mature mainstream	▪ Robust technology ▪ Not much evolution in vendors or technology	▪ Several dominant vendors
Legacy	▪ Not appropriate for new developments ▪ Cost of migration constrains replacement	▪ Maintenance revenue focus
Obsolete	▪ Rarely used	▪ Used/resale market only

Source: Gartner (July 2020)

Recommended by the Authors

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Understanding Gartner's Hype Cycles

Cool Vendors in Technology Innovation Through Power and Energy Electronics

Hype Cycle for Drones and Mobile Robots, 2020

Hype Cycle for Emerging Technologies, 2020

Hype Cycle for Automotive Technologies, 2020

Hype Cycle for Manufacturing Operations Strategy, 2020

Hype Cycle for Connected Vehicles and Smart Mobility, 2020

Hype Cycle for Edge Computing, 2020

Hype Cycle for Smart City Technologies and Solutions, 2020

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