GE Global Research

The GE Store for Technology

Contents

Welcome to GE Global Research, also known as the GE Store for Technology. Across our global network of nine technology centers, we have more than 3,600 of the world's best scientists and engineers driving advanced technologies for all of GE's industrial businesses. They are part of a global team of 50,000 technologists across the company driving GE's future every day.

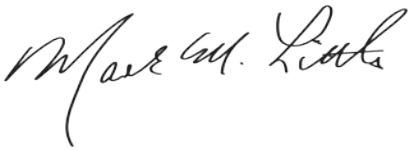
At Global Research, our scientists and engineers don't work for one business; they work for all of them. Their skills and expertise are applied wherever they're needed. Over time, they get exposure to projects with different GE businesses that allow them to readily transfer technical knowledge from one business to another. It's part of every GE researcher's DNA to think and act in this way.

The GE Store is a place where every business can come for technologies, product development and services that no one else can provide. The work of our researchers ties directly into the operational plans and product roadmaps of our businesses. GE business leaders meet with our technical leaders once every quarter to review their portfolios.

What you will see and read about in the following pages are key examples of the connections being made through the GE Store and their value to our businesses. At Global Research, we rarely ever start from square one on a new project. It was early testing of ceramic matrix composite (CMC) parts in Power & Water's land-based gas turbines in the early 2000s that helped us realize these parts could work in our jet engines for Aviation. The improved efficiency these parts enable is a big reason why our newest engine platform, the CFM LEAP, is the fastest selling engine in GE Aviation's history.

The story of CMCs is one of many across our portfolio that illustrate the knowledge, experience and broad scientific and engineering skillsets GE businesses can pull from within our GE Store for Technology to create new growth opportunities for the company. It is the innovation engine that drives everything we do.

Enjoy your visit to GE Global Research. We are excited to share what we are working on with you.



Mark Little

GE's new CFM-LEAP engine is the fastest selling commercial engine in modern history, and advanced technologies from the GE Store have played a big role in why. The engines contain CMC shrouds in the hot section and 3D printed fuel nozzles—both are firsts for jet engines and key to delivering unprecedented performance and efficiency.

Materials

Silicon Carbide (SiC)

Background:

In the early 1980s, GE ushered in a new era in energy conversion with the invention and realization of the Insulated Gate Bipolar Transistor (IGBT)[1]. Developed by GE, this power switching device would become the gateway for managing the flow of current for a very wide range of electrical systems. Today, a team of GE scientists is on the cusp of a new revolution in power management using a breakthrough material, silicon carbide (SiC).

For IGBTs and predecessor switching devices, silicon (Si) has been the workhorse material. But recent advances in SiC are promising a better material that will set new standards of efficiency and performance. For more than two decades, GE has been a leader in SiC technologies. We've demonstrated the world's best performance in power devices, advanced packaging and power electronic applications with this technology.

Power devices are the critical components in electronics that regulate how power is delivered and used. For power generation sources like wind and solar energy, they convert energy into usable forms for homes and businesses. In hybrid vehicles, they manage the electricity running through electric motors that affects driving range. And for data centers, they control how well power is used by the large scale computer systems that manage mass volumes of data.

GE business applications:

GE already has begun commercializing new SiC-enabled products for some power supplies in Aviation and is actively developing applications for products across multiple GE businesses. We're even launching a new start-up business to sell SiC into applications beyond GE, and a manufacturing partnership will enable us to supply high volumes of SiC devices. This will help to reduce overall costs and enable more widespread commercialization of the technology.

Future GE product applications include: smaller, more compact power devices to meet the increasing electricity needs of airplanes; more efficient conversion devices in applications like solar inverters to reduce power losses for solar and wind generation by half; new applications in hybrid electric vehicles that extend driving range by 10%; new solutions for healthcare imaging systems such as in MRI gradient drives for improved image quality and smaller footprint; more efficient tractions drives for GE Transportation; and enabling more efficient motors for oil and gas production.

To accelerate needed advancements, GE has become a lead industry partner in New York State's Power Electronics Manufacturing Consortium. GE is partnering with State University of New York (SUNY) Polytechnic Institute to build the world's most advanced fabrication line for manufacturing SiC power devices.

The new Albany-based fab will employ GE's proprietary technology to develop and produce best-in-class SiC devices that will revolutionize the power electronics industry. GE is contributing in excess of $100mm in IP and value to the consortium. To scale up the technology and reduce fabrication costs, manufacturing must move from the current industry standard of 4" wafers size to 6" wafers. The Albany Fab will be set up for 6" wafer production with the ability to increase to 8".

The GE Store difference:

Because of their clear line of sight to all of GE's business needs, GE researchers are developing revolutionary technology that will span several GE business applications. And much like we are doing with the GE – Fuel Cells start-up, we have the technical depth and industry breadth to build up a whole new business to serve the industry more broadly.

1. B. J. Baliga, "Fast-switching insulated gate transistors", IEEE Electron Device Letters, Vol. EDL-4, pp. 452-454, 1983.

Ceramic Matrix Composites

Background:

High temperature materials are vital to GE's turbomachinery, from gas turbines to jet engines. When you have materials that can handle higher temperatures, you can run your engine hotter or reduce the amount of cooling that you need to keep these materials from melting. These factors translate into higher engine efficiency and less fuel burn for our customers.

In the late 1980s, GE scientists began exploring ceramic matrix composites as an alternative to metal parts in its turbo machinery. The thought was simple: Ceramics inherently can handle hotter temperatures than metal and much lighter, but traditional ceramics are brittle by nature. What if you could engineer the ceramic in such a way that it had metal-like damage tolerance? Then you would truly have a watershed material that could set a new standard for engine efficiency and performance.

GE business applications:

Initially, the focus of GE's CMC program was to develop parts for power generation gas turbines. In fact, much of the early validation testing was done on gas turbines that we had already installed with customers. But with a more urgent need for the technology evolving in aviation, the program shifted to jet engines.

A first for jet engines: In 2016, GE's CFM LEAP engine for narrow body aircraft will go into service with the world's first CMC parts on a jet engine. Soon afterwards, GE's largest engine platform, GE9X for Boeing 777Xs, will go into service with multiple CMC components. As we continue to build more CMCs into our future jet engine platforms, attention has turned back again to gas turbines in our Power & Water business. Before too long, new generations of our gas turbine products will come with CMCs.

The GE Store difference:

It pays to have both the Power Generation and Aviation businesses make the investment and share in the development. Our Aviation business will run over 60 LEAP test engines and will conduct millions of hours of material testing. Our Power Generation business complements the test campaign by performing long-term engine tests with gas turbine customers. After logging over 30,000 hours of operation and generating more than 5 billion kWhr of electricity for residential and commercial use, we were convinced that we have a winning technology.

At GE, additive manufacturing is a cumulative set of tools such as 3D printing, cold spray and Direct Write (3D inking) *(shown here)* that we are applying throughout our manufacturing operations. By 2025, we expect additive manufacturing methods will be used in the design and manufacture of more than 20% of GE's new product concepts.

Manufacturing

Brilliant Factory

Background:

Across the Company, there is an exciting convergence taking place between Information Technology (IT) and Operational Technology (OT). The meeting of software and hardware is connecting factory floors to "The Cloud" and igniting a third industrial revolution in manufacturing.

At GE Global Research, we have a dedicated global team in advanced manufacturing working across GE's industrial businesses to transform our ~400 manufacturing and services plants into Brilliant Factories. We're combining our decades of experience in developing advanced manufacturing processes, sensors, and inspection and modeling tools with our deep expertise in operations, supply chain management, factory quality as well as IT tools and the software analytics now residing in the Software Center of Excellence in San Ramon, California to make this transformation happen.

At the same time, we're increasingly working with industrial, academic and government partners outside GE in the US and around the world to advance this next evolution in manufacturing. We are seeing a rise in manufacturing ecosystems that will speed up innovation and adoption, and are actively engaged to open up supply chains to new players and technologies.

GE business applications:

GE's advanced manufacturing team is working across all of GE's businesses to transform our manufacturing operations with the right tools and processes across the broad spectrum of factory operations that exist within GE. We're enabling factories to be constantly learning, continually optimizing their throughput, productivity and efficiency, and providing valuable feedback to our design teams to enhance the next set of product and service offerings. This involves digitally connecting all parts of the manufacturing supply chain from the engineering teams to the factory floor and suppliers to the service shops. We want to create a continuous loop of data sharing and feedback between all of these teams and operations that will enable real-time decision-making and feedback on how to improve a manufacturing process or even the product itself.

We currently have dozens of pilots underway at a variety of manufacturing facilities, testing out tools, analytics, software, IT infrastructure, and optimization platforms. These pilots validate the technology and impact, and then are rolled out across factories with similar missions and needs. Pilot proof-points are increasing monthly as we learn, build and succeed in the building blocks of our vision.

Examples include:

- Development of a real-time scheduling system that allows us to adjust part flow decisions every day to ensure on-time delivery of our products. This app is now being commercialized through GE's Intelligent Platform (IP) business. It will be scaled up within GE and with strategic partners.

  In multiple facilities across the globe we have connected equipment virtually to continuously monitor and optimize processes at the machine level, flow through the factory, maintenance operations, and special handling for customer needs. Technology was needed to do this as the machines did not all have the capability to measure what was needed, they did not naturally link together within a virtual system, and the optimization was not automated before our activities. These efforts exemplify how IT and OT can work together to make a real difference!
- In GE's turbomachinery businesses (Aviation, Power & Water, Oil & Gas, and Transportation), GE researchers have developed an app to ensure that products being designed are producible. When a designer is creating a part, the app will provide real-time feedback on whether the part is producible and what features will add cost or manufacturing pinch points. This data is collected daily from our factories and turned into design rules; these activities are integrating engineering with the supply chain in new and innovative ways. Ultimately, the app will enable our turbomachinery businesses to move products to market faster and at lower cost. In some cases, we have reduced manufacturing engineering times by more than 80%.

The opportunity is not trivial. A one percent improvement in productivity for GE's manufacturing operations represents a savings of $500 million. With GE's Brilliant Factory vision, we're focused on achieving a 20% improvement in productivity and efficiency.

The GE Store difference:

With a line of sight and direct connections to our business supply chain partners in every GE business, we are working across every business to implement new elements of the brilliant factory vision. Each pilot, new "app", advanced technology or process will be developed, optimized and categorized for its impact as a function of the type of operation, and then directly translated to other businesses and factories where similar operations exist. The few examples shown are the model for all of these activities—learn deeply in one operation/process/factory and then rapidly deploy these lessons across the company.

Additive Manufacturing

Background:

Additive manufacturing has become one of the most highly touted and talked about fields in recent years. For scientists and engineers at GE Global Research, it has been a more than 20-year research odyssey that today is culminating in exciting developments that are helping to transform our products and our manufacturing operations.

For many people, additive manufacturing is synonymous with 3D printing. At GE, additive is 3D printing but also a much broader tool kit of processes such as cold spray, direct write and electron beam technology that represent different ways of "building up" parts. Moreover, additive manufacturing itself is much more than just printing parts. GE uses additive throughout its manufacturing operations, from rapid prototyping and testing new designs to developing new tooling. By 2025, we expect additive manufacturing methods will be used in the design and manufacture of more than 20% of GE's new product concepts.

GE business applications:

Next year, GE's Aviation's CFM LEAP engine will enter into service with the world's first 3D printed parts in the functional part of the engine. Each engine will have 19 3D printed fuel nozzles installed that are far more sophisticated in design, yet simpler to produce and more efficient than than conventionally-produced nozzles. With well over 8,000 engines on orders, GE will print more than 100,000 metal parts by 2020. This experience with part development and industry scale-up for Aviation is beginning to translate quickly to other parts of GE's business portfolio.

Much of what GE has acquired in component design, materials and manufacturing process expertise for GE Aviation is being shared with GE's Power & Water business to jumpstart their additive efforts. GE Power & Water is developing 3D-printed parts for its H-Turbine gas turbine platform to deliver improved efficiency and performance. New 3D designs are enabling part configurations that could not be made conventionally. Through the use of Global Research and the Advanced Manufacturing Works facility located in Greenville, South Carolina, Power & Water is accelerating their efforts towards this technology.

In addition to Power & Water, GE's additive researchers have spread their knowledge and development of new additive tools to GE Oil & Gas and also GE Healthcare. In GE Oil & Gas, for example, 3D printing is being used to develop specialty parts such as control valves used in harsh environments.

The GE Store difference:

Additive manufacturing started as a research endeavor and has rapidly evolved into a cross-business technology platform where best practices and new developments can be shared from one GE business to another. New material and manufacturing processes that might have otherwise taken years can now be transferred and adapted in a matter of months or even weeks. That's the power additive manufacturing is bringing to GE's business portfolio.

Composites Automation

Background:

Composites have been a breakthrough material for GE's aircraft engines and nacelles, wind blades and offshore riser pipes. With a higher strength-to-weight ratio than metal, composites translate into big savings on fuel and lower emissions. GE engineers are now utilizing robotic and automated fiber placement technology (AFP) along with data analytics to drive more efficient, cost effective and high quality manufacturing for both polymer matrix and ceramic matrix composites.

Composites manufacturing is a complex process from laying up the raw material to final part formation. Today most of the parts are made using a hand layup process and integrated process analytics to enable the consistent production of high quality parts. GE has accumulated significant experience in manufacturing composites with complex shapes and sizes over the last three decades. As we look to provide even more benefit to our customers, the challenge today is finding ways to manufacture composite components faster and cheaper. This has led to automation.

GE business applications:

This year marks the 20th anniversary that GE's composite fan blade was certified for the GE90 engine. This marked the first Aviation use of revolutionary composite fiber polymeric material on a jet engine's front fan blade that stands as a unique feat today. Another first for jet engines will be the introduction of the Passport 20 fan case in 2016 for the Bombardier 7000 business jet, which will be manufactured using automated fiber placement (AFP). Soon to follow that will be some of GE's nacelle components for the Boeing 747-8 and Airbus A320. AFP technology allows design flexibility, consistent ply placement/compaction resulting in high quality, along with substantial savings in materials and labor. With complex shapes and multi-material systems, GE is paving the way for robotic automation through its use of technologies ranging from pick and place to filament winding and fiber placement.

The GE Store difference:

The experience with automation on engine components provides the technical confidence and knowledge that it can be applied to wind blades, nacelle components and in the future to composite flexible riser pipes for oil and gas production.

Phosphors

Background:

Light emitting diodes, or LEDs, are transforming the lighting industry with ever higher efficiency and functionality. But even with LEDs, lighting designers face a choice: Enhanced efficiency or enhanced color quality? Customers, of course, want both. The key, GE scientists believed, resided in developing better materials to convert blue LED light into red light. With the new TriGain* phosphor system, material scientists and chemists at GE Global Research and GE Lighting have delivered a novel solution that overcomes this trade-off to make lighting systems that lead the industry in both efficiency and color quality. GE Lighting has partnered with Nichia to integrate LEDs with the TriGain phosphor system into products with high efficiency, color quality, and simpler system designs. Beyond lighting, the TriGain phosphor system is now also used in LCD display for phones, tablets, and TVs to give similar advantages in color, efficiency, and system design.

GE business applications:

The TriGain phosphor system is enabling many exciting new products for GE Lighting and GE Ventures including:

- Lighting fixtures for retail and commercial customers requiring high color quality
- Replacement lamps for retail, commercial, and consumer customers
- Licensing TriGain technology for display applications
- TriGain phosphor materials to designated licensees for display usage

The GE Store difference:

The development of optical materials like phosphors is a critical expertise at GE Global Research that impacts multiple GE businesses. Earlier work on GE Lighting phosphors led to the discovery of a new scintillating material for GE Healthcare that was introduced in 2009 in the Discovery CT750, a high-definition Computed Tomography (CT) scanner. This new material enabled a CT scanner that produced images 100 times faster while also improving the image quality of diagnostic images. Similarly, the collaboration between GE Ventures, GE Lighting, and GE Global Research has accelerated the commercialization of TriGain LED phosphors into both lighting and consumer display markets.

Water (REMIS)

Background:

When GE scientists were looking to help GE Power & Water optimize desalter operations to enable refineries to more efficiently and effectively process opportunity crudes, they needed to look no further than GE's Healthcare business for the answer. While treating water for hydrocarbons seems a far cry from treating patients in healthcare, the technology tells a different story.

At Global Research, GE scientists have been developing increasingly sensitive and selective sensors that support applications in a wide variety of GE's industrial businesses. Resonant enhanced multivariate impedance spectroscopy (REMIS) sensors are one such platform.

GE business applications:

Originally developed for GE Healthcare to monitor critical manufacturing parameters in single-use biopharmaceutical manufacturing, GE scientists are now adapting these REMIS sensors with GE Power & Water for the Integrated Solutions for Refining (ISR) initiative. In the refinery setting, REMIS sensors will be deployed as an industrial probe to quantify water and oil compositions of complex emulsions with the durability to handle tough environmental conditions, corrosion, fouling, and drift; this will enable better control of the application of our proprietary Chemical Portfolio used to treat both hydrocarbons and water.

Beyond GE Healthcare and Power & Water, the transfer of GE's REMIS sensor technology will flow to other businesses as well. GE Transportation will leverage this platform to detect contaminates in lubricating oils, and GE Licensing has demonstrated value in detecting gases used for sterilization in medical device packaging and other opportunities outside of GE's core businesses.

The GE Store difference:

The REMIS platform has led to sensors that are being deployed for applications in GE Healthcare, GE Power & Water, GE Transportation, and GE Licensing. It's a great example of how common technology platforms developed at GE Global Research can be rapidly transferred across many GE business platforms.

Industrial Inspection

Background:

In healthcare, GE researchers are driving advanced technologies in medical imaging and diagnostics to help doctors spot disease earlier using non-invasive or minimally invasive imaging procedures. Over many decades, GE Healthcare has pioneered many industry firsts and breakthroughs in a variety of imaging modalities from X-ray and ultrasound to CT, PET and MR imaging. Whether imaging a patient to look for disease or checking an industrial part to see if it is cracked or damaged, the goal is the same: We want to help doctors or factory engineers make that diagnosis with as little disturbance as possible to the subject at hand.

GE business applications:

At GE Global Research, it's not unusual to find teams of scientists and engineers who work on both medical imaging and industrial inspection technologies. Indeed it was from Healthcare that we created and built a whole business around Industrial Inspection. Today, the examples of how Healthcare technology has been applied to GE's other industrial businesses are numerous and growing more every year.

Computed Tomography (CT): In hospitals, we use CT to non-invasively see inside patients to diagnose cancer or cardiac health. At GE Global Research, we're applying the same technology to non-invasively inspect parts and equipment that make up our products. A great example is in Oil & Gas, where we are using CT to analyze rock samples involved with oil exploration. We're also using CT to inspect LEAP engine blades and high temperature composite parts for Aviation. We're even using CT to look at the chemistry of our energy storage batteries and study the properties of new materials being developed for an array of GE products.

X-Ray: GE Healthcare's Digital Radiography detectors, originally developed for cardiac imaging and mammography systems, have been adapted for industrial x-ray inspection. GE Measurement & Controls (M&CS) is using these detectors for inspection across many applications in GE's Aviation and Power & Water businesses.

Ultrasound: GE Healthcare has extensive experience in developing phased array ultrasound probes and systems for medical imaging applications. This technology has been adapted for the development of industrial non-destructive testing devices, such as the Phasor series ultrasonic flaw detectors from GE M&CS that are used for many factory floor and field inspection applications, spanning welds, forgings, castings, bridges, and rail inspection.

The GE Store difference:

With decades of in-house medical imaging knowledge and a proven portfolio of imaging products, GE has been able to readily transfer imaging knowledge from Healthcare to support and create a multitude of inspection applications for our industrial businesses.

Industrial Internet

GE scientists and engineers are pairing our software and analytics expertise with our deep understanding of GE's products from the design and manufacturing phases to create a digital model of each and every machine we deliver to our customers. The "Digital Twin" is a foundational analytic that will be used as part of many value-added applications for customers across all of GE's businesses.

Digital Twin

Background:

GE is creating physics-based analytics to bring increased insight into every asset. To do this, GE engineers and scientists are applying our deep understanding of GE products from the design and manufacturing phases to create a digital model of each and every machine we deliver to our customers.

These Digital Twins are living digital models that are continuously updated as a machine operates and learns from its sensors. Through these models, we can know the remaining useful life of key parts within the machine, without disrupting operations. At times, we also may obtain rich information from the machine, especially during planned inspections and maintenance. This information allows GE to compare and refine the model's ability to predict the health of the machine at any point in time.

As our machines operate around the world in various ways and in various conditions, GE is perfecting the art of modeling machine health. We have created a Digital Twin of the machine that is the foundation for the brain of the machine, a brilliant machine that is continuously aware of its own health and can imagine its future health under any future conditions and advise its owner on the best outcome. For example, the Digital Twin is used to optimize the economics of our customer's operations, which includes avoiding unplanned downtime.

Building the Digital Twin combines many technologies including: Data science; big data; materials science; physics; estimation; optimization; controls; digital architecture; and user experience. GE researchers live at the intersection of these physical and analytical sciences, bringing big data and big iron together for big value for our customers.

GE business applications:

The Digital Twin is a foundational analytic that can be used as part of many value-added applications for customers across all GE businesses. These include product configuration, optimal parts tracking and replacement, machine performance optimization, prognostics, decision support, field services, and more. The Digital Twin will bring new services to our customers as well as allow GE to execute on existing services more efficiently and effectively.

GE is building the software architecture, data lake, model infrastructure, visualization, and applications on our Predix* platform to enable the Digital Twin to be deployed at scale across multiple industries and businesses.

GE is first applying this technology to our Aviation business for large commercial aircraft engines. In-flight sensor data is used to update and personalize a performance and thermal model. This model will then be used to gain detailed insights of the stress and life of the parts inside of the engine. From that, we can schedule the optimal time for part replacement.

Next, GE will apply this technology to update and personalize performance and thermal models in gas turbines. Here, the control system employs the information from the Digital Twin to operate the gas turbine in a manner that optimizes economic output while managing risks associated with avoiding unplanned downtime.

The GE Store difference:

The GE Store is a place where we create through collaboration. At Global Research, the greater value comes from our ability to rapidly form multidisciplinary teams that bridge our deep domain expertise in the physical sciences with our great strength in software and analytics. Both were required when creating the Digital Twin.

Controls Convergence

Background:

Controls are the computers or brains on every industrial machine that ensure safe operation, while allowing it to behave as directed by the operator. Today, GE researchers are taking automated controls beyond what they do in our products today to enable truly "brilliant machines" that raise their performance to new heights.

This vision is bold and would not have been possible even a few years ago. But rapid advances in high-performance computing, software and analytics have put this vision squarely within our sights. For starters, these advances have allowed us to embed more knowledge within the machines themselves. Then, harnessing cloud connectivity and the power of our new software platform called Predix, we're connecting every GE machine to the cloud. Finally, we're implementing a common communications platform and robust security into every GE asset, so that all our machines, whether a gas turbine or wind turbine, can talk the same language. This will enable "plug and play systems" that allow us to leverage the scale of GE offerings into solutions while getting substantial reductions in commissioning and engineering requisition time.

GE business applications:

GE's Wind business has been an early adopter of advanced controls technology that has enabled the business to improve the energy capture of its 1.6MW-100M wind turbines by 20% while also lowering materials costs on the manufacturing side. Using a family of technology called model-based controls, we can model the physics of what happens to wind turbines under varying wind conditions. We can analyze factors like stress on the turbine tower or what the optimal pitch of a wind blade should be to maximize wind capture. By accurately predicting what will happen, we can then design special control features in the turbine that enable the turbine to adjust to changing conditions on its own for peak performance. In the case of the 1.6MW–100M, the pitch of the turbine's blade will automatically adjust to capture wind in the most advantageous way while mitigating the impact of stress incoming winds place on the tower. By relieving stress, these turbines can be manufactured with materials that are lower in cost to help make wind energy more cost competitive.

GE is using model-based controls in our Transportation business as well to improve how trains are driven. Taking our knowledge about the train, the tracks, and the inter-car forces and stresses of operation, we created a product called Trip Optimizer that is now used by major railroads all over the world. It is essentially smart cruise control for trains that is delivering a sustainable 10% fuel savings on average per train.

The GE Store difference:

Controls technology is allowing GE to take our physics, domain, and operations knowledge and apply it in real-time on our machines. Almost everything we sell uses a control system to manage the operation of the asset. Across the businesses, GE's controls expertise is broad and deep. Creating a common, advanced controls platform for all of the GE businesses to draw upon is unlocking a new "plug and play" world where we can take a solution for one business and readily transfer it to another. The end result is already proving new levels of competitiveness and new classes of services for our assets.

Predix* (APM)

Background:

By combining intelligent machines, advanced analytics, and people at work, the Industrial Internet enables companies to move from reactive to proactive and predictive maintenance, achieve operator consistency, and avoid surprises, which can ultimately drive key business outcomes. GE Software is helping customers to achieve outcomes by harnessing the power of the Industrial Internet through Predix. Predix is the cloud platform for the Industrial Internet upon which developers can build and deploy industrial strength apps such as for Asset Performance Management (APM) to help businesses optimize assets, fleets, and overall operations.

Predix combines an industry-leading stack of technologies for distributed computing and big data analytics, asset data management, machine-to-machine communications and mobility. The platform extends beyond GE assets to connect machines from any vendor or vintage. Additionally, in 2015, as Predix is made available beyond GE, technology partners, developers and customers will be able to develop their advanced analytics and applications for use across the world of industry creating an Industrial Internet ecosystem.

GE business applications:

Asset Performance Management (APM) is a new discipline leveraging the integration of operations data, predictive analytics, historical asset catalogs, and user experience for the purpose of maximizing asset reliability, reducing cost and risk, and unlocking new growth opportunities. Actionable insights gained allow asset-intensive companies to more efficiently operate critical assets that drive their business objectives. GE Software is enabling processes-embedded diagnosis, enabled by insights into operational industrial business processes and machine-specific operational conditions and physical parameters, for meaningfully differentiated Monitoring and Diagnostics capabilities.

Receiving input from GE's industrial businesses, the GE Software team is ensuring we deliver horizontal capabilities around Monitoring and Diagnostics as a service. In turn, the GE businesses can leverage this APM and Predix technology to explore new commercial opportunities to service their customers with value-based solutions.

The GE Store difference:

Delivering Asset Performance Management software services and analytics is allowing GE to take our data science, domain, and operations knowledge and apply it in real time to help optimize customer operations. By providing a common set of Monitoring and Diagnostics software services on the modern Predix Industrial Internet cloud platform, we are enabling the GE businesses to extend their capabilities for specific customer needs. With Asset Performance Management available in a modern, multi-tenant, cloud-based architecture, the GE businesses can deliver customers immediate value and expand our reach from simply GE assets to the systems that support them. The end result is already proving new levels of competitiveness and delivering insights to customers that GE can deliver.

Distributed Health – Ultrasound

Background:

Imaging continues to transform Healthcare, providing a window into the patient that aids physicians in developing diagnoses, delivering therapy and monitoring response. The challenge today is making it more accessible and expanding its application at all levels of healthcare, from hospitals to smaller clinical settings. Ultrasound imaging provides an ideal pathway for expanding our reach in both areas.

Already, we have seen the way ultrasound miniaturization has put high-tech imaging technologies into the hands of new users such as primary care physicians, as well as into regions of the world where these technologies are scarce. GE's Vscan, a cell phone sized device that you can fit in your pocket, is a great example of technology that is providing doctors with more affordable, mobile tools to deliver care in more places.

Advanced ultrasound technologies, such as 4D imaging, are also making ultrasound easier to use. GE scientists have developed 4D Ultrasound imaging technologies that capture 3D images in such rapid succession that motion is frozen, which provides a clearer image. Each 3D image covers enough anatomy to simplify operation of the system. These advances have greatly alleviated concerns of motion and ease of use in heart imaging. And along with improved imaging, advances in visualization and image analysis have further eased interpretation for clinical personnel.

GE business applications:

4D Ultrasound is available on GE's Vivid, LOGIQ, and Voluson product lines, addressing cardiac, general imaging, and women's health applications for fast, simple and precise diagnosis. Advances in electronics and computing may someday allow these technologies to be available on GE's Point-of-Care and Primary Care Ultrasound equipment for guidance, screening and distributed health.

The GE Store difference:

Advances in miniaturization benefit the entire Ultrasound product line. Advances in imaging with the presence of motion that start in our premium cardiac systems flow down to our general imaging and women's health products. And advances in visualization addressing ease of use are driven by our women's health products and flow down to our general imaging and cardiac products.

Ultrasound imaging is not just a Healthcare technology. Ultrasound is shared across our manufacturing and service industries: Aviation, Wind, Oil & Gas. For example, composite materials for Aviation parts are inspected using ultrasound during the manufacturing process.

Service Robotics

Background:

Service Robotics is a new class of intelligent machines that represents another window to increased productivity, safety, and efficiency in our factories, hospitals and fleets. Service robots will allow us to operate anywhere, at any time, and amplify our capabilities in dull, dirty and dangerous environments. They will serve as information gatherers that can safely interact with assets, systems, and people.

GE business applications:

GE is developing Guardian, a Field Service Robotics platform that can operate in industrial environments to address the 3 D's described above. Rather than just building a robot, GE Global Research is focused on developing a complete end-to-end solution that addresses very specific challenges in industrial environments.

The GE Store difference:

Robotics may be applied across all of GE's industrial portfolio. It is a cross-disciplinary field combining innovations from across GE Global Research including: sensors, controls, power management, computer vision, mechanical systems and autonomy. Advancements in robotics for one industrial domain can be rapidly adapted to others.

Energy

Drawing upon combustion expertise from GE's Aviation, Power & Water, Oil & Gas and Marine business, GE was the first to build a locomotive that met the EPA's mandate of Tier 4 emissions. Moreover this was accomplished without the need for costly aftertreatment systems, which was once thought impossible by the diesel engine community.

Combustion/Tier 4

Background:

For more than 100 years, GE scientists and engineers have pushed the boundaries of combustion technology, spawned new industries for GE and pushed efficiency and performance of turbine engines to new heights. It was Dr. Sanford Moss, a GE engineer in the late 1800s and early 1900s, whose development of the "turbo supercharger" led to the launch of the company's gas turbine division and later, its Aviation business. GE's reciprocating engine products in Transportation for locomotives, in distributed power spaces such as our Jenbacher gas engines and in Oil & Gas for oil and gas production also are well established.

GE business applications:

Recently, our freight locomotive business faced and met the challenge of achieving the difficult EPA mandate of Tier 4 emissions that became effective in January 2015. Consensus in the diesel engine community was that it would be impossible to meet these new emissions regulations without the use of aftertreatment systems. This would require hundreds of millions of dollars in new investments by railroad companies to comply.

Applying significant learnings from compressor and turbine technology developments as well as emissions reduction know-how from our Marine business, GE Tier 4 solution was able to meet the new Tier 4 standards without the need for aftertreatment technologies. This solution involved 27 patent applications, of which 14 already have been granted.

To date, more than 1,000 orders have been placed for GE's Tier 4 freight locomotives.

The GE Store difference:

The Tier 4 Locomotive solution significantly leveraged learnings from compressor and turbine technologies we were developing for our Oil & Gas business as well as emissions reduction know-how from our Marine engine business. These performance "recipes" have in turn been made available to our Distributed Power business and are being applied to the new Series X gas engine.

Fuel Cells

Background:

GE – Fuel Cells is in an internal start-up developing solid oxide fuel cell systems that provide businesses and communities around the world the ability to efficiently generate clean, reliable power locally at the point of use. This opportunity is enabled by an advanced manufacturing breakthrough and innovative hybrid system design developed at GE Global Research.

Conventional wisdom tells us that energy efficiency will rise as your power system scales up in size. The performance of GE's hybrid solid oxide fuel cell solution has turned this concept on its head. Pairing GE's solid oxide fuel cell (SOFC) technology with our natural gas engines, this hybrid system can achieve efficiency levels of 65% in a distributed power package.

GE business applications:

This new GE start-up in distributed power is projected to provide:

- 1-10 MW of power
- Projected 60-65% system efficiency
- Ultra low emissions
- On-site energy to provide critical power in case of grid disruption

To fast track GE's Hybrid SOFC solution to market, GE created this new start-up under GE Ventures. Typically, the launch of a new industrial business can take years. Using GE's FastWorks model, GE – Fuel Cells has built up a team and robust pilot manufacturing operation within months.

The GE Store difference:

GE – Fuel Cells has the speed and agility of a small start-up, yet has access to the breadth and strength of GE. By leveraging technology from GE Global Research, operating tools and processes from the businesses and with access to world class experts, supply and market channels, we are able to advance at a rapid pace.

Oil & Gas Rotating Machinery

Background:

As Oil & Gas production moves to tougher, harder-to-reach environments, oil and gas turbomachinery has to deliver higher performance in power and efficiency, with a reduced footprint and weight. Additionally, some of these systems must handle harsher mixes of gas, liquids, and other constituents that present additional challenges. To address these difficult problems, it helps to have a proven team of world-class experts in fluid-dynamics, thermal, combustion, advanced materials and metallurgy that bring decades of experience solving similar technology challenges for other forms of turbomachinery that GE makes for its Aviation and Power & Water businesses.

GE business applications:

Power density gas compression, multi-phase flow pumping and gas turbine technology are three areas impacting the vast range of GE Oil & Gas turbomachinery product lines.

- In power density, we're translating aerodynamic, bearing and rotor dynamics technology from Aviation to enable a new class of smaller footprint, higher efficiency gas compressors.
- In multi-phase flow, we're developing more sophisticated designs for pumping turbomachinery to handle the widest range of oilfield conditions. Originally developed for GE Oil & Gas' electrical submersible pump (ESP) product, this technology is now being developed for a new subsea pump to fill out its centrifugal pump product line.
- In gas turbines technology, we are leveraging our high efficiency, low emission combustion, proven hot gas path technology and advanced aerodynamic concepts to create the NovaLT16 gas turbine with best-in-class availability, efficiency and operability. This product is especially designed for demanding pipeline applications in remote areas, where longer maintenance intervals (up to 35k hrs) are attractive.

The GE Store difference:

GE draws heavily on its vast turbomachinery portfolio to accelerate technology introduction into new product lines. Gas compression technology advances for Oil & Gas make use of computational fluid dynamics techniques developed for GE Aviation and proven on helicopters turboshaft fleet. This same technology is being introduced simultaneously into GE's customized low pressure turbocharger on GE Transportation's new Evolution Series Tier 4 Locomotive. Material and hard coating developed for aircraft application have been migrated in to multiphase compressor and pumps with heavy sour and acid contaminants increasing the life of components. Reliable gas turbine technology such as combustion, compression and durability draw from our demonstrated field experience in aircraft propulsion and power generation technology. Finally, even our newest acquisitions such as ESPs can be rapidly leveraged to create new product capabilities in new spaces such as subsea pumps.