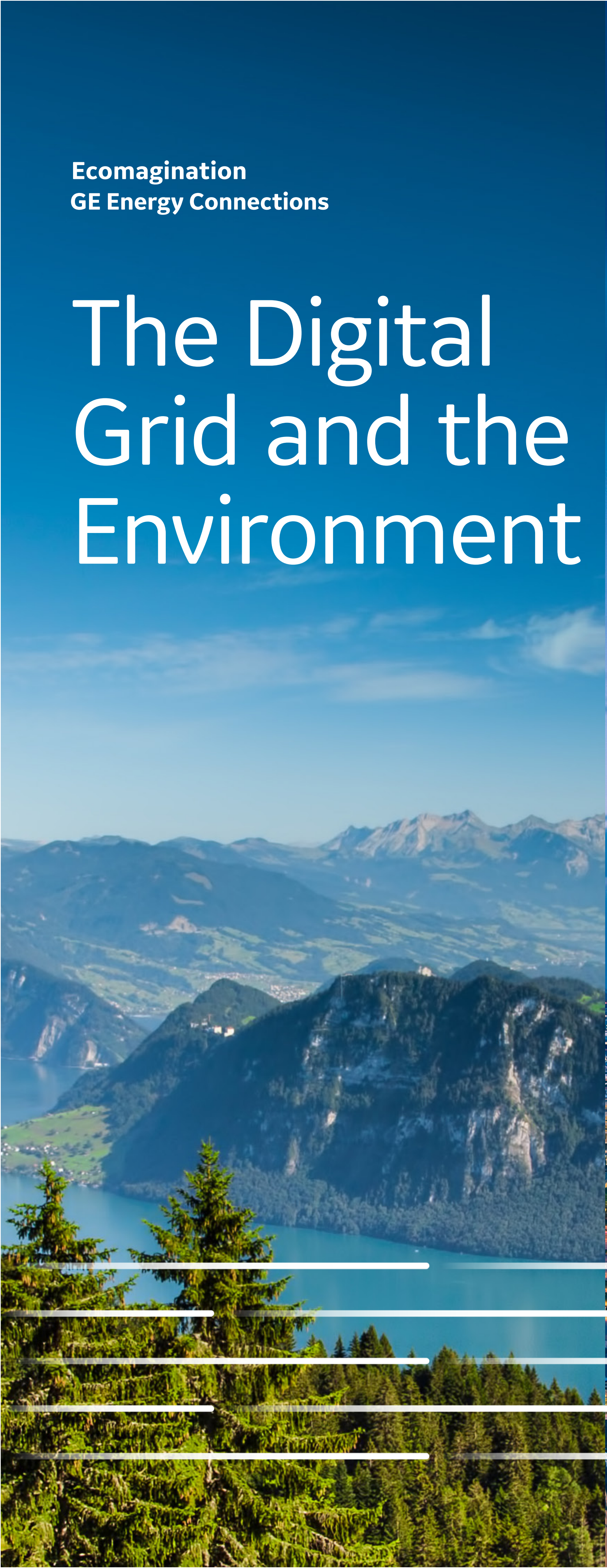
Ecomagination
GE Energy Connections

The Digital Grid and the Environment



New solutions are enabling a cleaner and more efficient global power system

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INTRODUCTION

> “GE Ecomagination is about creating innovations that make both economic and environmental sense for our customers. GE’s digital grid technologies are the essence of what Ecomagination is all about.”
>
> – Debora Frodl, GE Ecomagination Executive Director

In many parts of the world, the electric transmission and distribution (T&D) systems are over a century old. There are a host of conventional power system tools and technologies that have evolved throughout time that are used to manage the daily operation, and continued growth, of electricity grids around the world. These tools include a portfolio of digital tools that are distributed throughout the system. These tools range from protection relays and substation controllers in the periphery, to power plant controls, and all the way up to utility energy management platforms in the operating centers. For industry stakeholders, there is no question that an impressive level of intelligence is already deployed in modern grids, enabling the coordinated operation of interconnections that represent the most complex machine ever built by humankind.

Nonetheless, the pace of innovation in the digital world offers a unique opportunity to revisit grid infrastructure and to explore the application of newly emerging digital tools to extract more value from the existing infrastructure, as well as be more efficient in the deployment of new assets. The smart pairing of these emerging digital technologies with the conventional physical and digital tools already available in the grid creates an opportunity to transform global T&D systems to deliver important outcomes, such as:

- Improved reliability;
- An improved ability to integrate greater levels of renewable energy resources; and
- Enhanced utilization of existing and new infrastructure, and hence better economic returns.

The latter two outcomes, while economically powerful, also bring the added benefit of reducing the environmental impact associated with electricity production and delivery. A report by the Pacific Northwest National Laboratory (PNNL) estimated that digital grid technologies have the potential to reduce electricity-related carbon dioxide (CO_2) emissions in the United States by up to 12 percent by 2030.[1] If this number is scaled globally, that’s equivalent to reducing global CO_2 emissions by 2 billion metric tonnes per year by 2030.

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[1] Pacific Northwest National Laboratory. (January 2010). *Smart Grid: Estimation of the CO_2 Benefits.*

This is the same carbon impact as taking half of the passenger cars in the world today off the road.

Connecting new renewable energy resources to the grid will require significant investments in T&D infrastructure. To make these investments economical, it is imperative that they include thoughtful consideration to the way the grid is operated, making the best use of the flexibility of installed and new assets to compensate for the variability of these resources. Moreover, investment decision makers should cast a wide net when considering the tools to be deployed for realizing expansion of the power delivery capacity. Non-wires alternatives, coupled with deeper and faster intelligence governing the operation of the grid, can allow significant growth in capacity to come from within the infrastructure already deployed, as well as to help new infrastructure be sized with an expectation of higher performance.

Digital grid technologies that benefit the environment call for a smarter, more aggressive operation of the grid that pushes closer to limits by taking advantage of a much better understanding of the real-time state of the network. These tools do not reside in singular locations of the grid; instead they are stitched together into solutions that deploy the right intelligence throughout all levels of the grid. The intelligent fabric that extends from control systems on generation assets, through utility operations centers, and into a new and powerful cloud resource is the digital grid, and it is an essential part of the energy ecosystem of the future.

GE is a proven leader in both grid solutions and environmentally-focused technology offerings. GE's Ecomagination program is a dedicated business strategy aimed at developing and deploying technology solutions that make both economic and environmental sense for our customers. GE Energy Connections' Grid Solutions business has helped 90 percent of the world's transmission utilities deliver power reliably and efficiently to their customers. By combining the power and intent of GE Ecomagination's program with the digital solutions from GE's grid solutions portfolio, GE is focused on maximizing the potential of innovative grid technologies that has a positive environmental impact for businesses, people, and the planet.

> "GE Energy Connections provides solutions that make the conversion and delivery of electricity more productive by increasing throughput and efficiency. Our evolving portfolio of digital grid solutions provides new tools for our customers to run their systems more optimally, while at the same time improving their carbon footprint."
>
> – Juan M. de Bedout, CTO, GE Energy Connections

CATCHING THE DIGITAL WAVE

The toolbox used by planners and operators of modern electric grids has an impressive array of physical and digital tools. Key physical tools include high voltage and medium voltage equipment, Alternating Current (AC) transmission and distribution lines, Flexible AC Transmission Systems (FACTS) tools to improve AC power system stability and transfer capacity, and high voltage DC transmission technologies, to name a few. Key digital tools in common use include protection relays, substation controllers, Phasor Measurement Units, transmission Energy Management Systems (EMS) and Market Management Systems (MMS), Distribution Management Systems (DMS) and Distributed Energy Resource Management Systems (DERMS). These tools exist as part of complex systems, interacting directly or indirectly throughout the electricity value chain.

The emergence of digital grid solutions is driven by broader advances in information and communications technologies (ICT) and the development of the Industrial Internet. The blending of digital and physical assets in industrial operations can be traced back to 1959, when Texaco's Port Arthur refinery became the first chemical plant to use digital control. Since then, software has become increasingly integrated into industrial operations; in the 1960s, the first generation of industrial software used large minicomputers with no connectivity to other systems. By the 1970s, second-generation software systems were in place that were distributed across multiple connected stations. Grid operators were keen to follow; in 1982 GE introduced one of the industry's very first digital protection relays, followed in 1985 by its first communicating digital relay. In 1990 GE launched the industry's first open architecture digital transmission EMS, the XA/21. See Figure 1.

FIGURE 1: INDUSTRIAL INTERNET TIMELINE

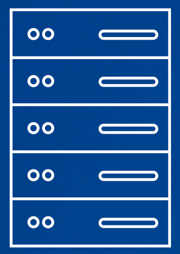
Industrial software systems have evolved over the last 50 years from monolithic systems that provided machine-level control, to today's Industrial Internet, which facilitates resource optimization for global industrial networks.

1950s–1960s

Monolithic

Enabled Machine-Level Resource Optimization

The first generation of industrial control software used large mini-computers connected to industrial machines with no connectivity to other systems. They had limited security.



1950 1960

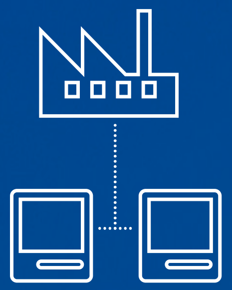
- 1959
  Texaco's Port Arthur refinery becomes the first chemical plant to use digital control.

1970s–1980s

Distributed

Enabled Facility-Level Resource Optimization

The second generation of industrial control software was distributed across multiple independent workstations connected through proprietary communications protocols. They had limited security.



1970 1980

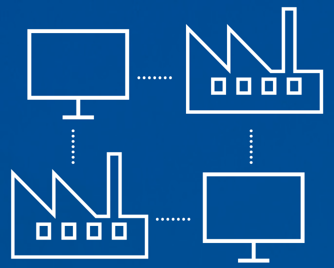
- 1969
  The first nodes of what will become the Advanced Research Projects Agency Network (ARPANET) are established. ARPANET was the precursor to today's Internet.
- 1982
  The Internet protocol (TCP/IP) is established. This standard enabled seamless communication between interconnected networks.
- 1985
  The number of hosts on the Internet (all TCP/IP interconnected networks) reaches 2,000.

1990s–2000s

Networked

Enabled Enterprise-Level Resource Optimization

The third generation of industrial control software were distributed and networked, and computers could be interconnected through a secure local area network (LAN). The systems spread across multiple LANs and across geographies.



1990 2000

- 1990
  The Internet grows to over 300,000 hosts.
- 1991
  After the ARPANET project was concluded, all commercial restrictions on the use of the Internet are removed.
- 1994
  The concept of the Internet of Things (IoT) is first developed. The basic idea was to affix sensors to common objects in order to connect these items to the Internet.
- 1999
  The Massachusetts I institute of Technology (MIT) establishes the Auto-ID Center to conduct research focused on IoT. During the same year, the world's first machine-to-machine protocol, MQ Telemetry Transport (MQTT), is developed.
- 2008
  The first international IoT conference takes place in Zurich.

2010s–Today

Industrial Internet

Enables Global Network Resource Optimization

Over the last decade, cloud computing, network bandwidth increases, hardware improvements, and software advances have enabled the emergence of the Industrial Internet.

2010 2020

- 2010
  The number of Internet hosts exceeds 800 million.
- Improvements in information technologies enable the IoT to be applied to industrial machinery.
- 2012
  GE announces its commitment to a $1 billion investment in software and analytics and launches the Software and Analytical Center of Excellence in California.
- 2013
  GE develops Predix™, the first software platform for the Industrial Internet.
- 2014
  GE's portfolio grows to 31 Industrial Internet applications within its Predictivity suite of solutions using the Predix™ platform. The Industrial Internet Consortium is established to further the development, adoption, and widespread use of the Industrial Internet.
- 2015
  GE releases Predix™, the operating system of the Industrial Internet. Predix™ is a cloud-based platform designed for building and powering industrial-strength applications.
- 2015
  GE and Intel joined forces in order to leverage the power of ICT to help solve the world's toughest global natural resource challenges.
- 2016
  Intel scales its architecture for IoT through a wide range of product offerings. Intel® Quark™, Intel Atom™, Intel Core™, and Intel Xeon® processors each support a wide range of performance points with a common set of code, analytics, encryption, and new application requirements in IoT.
- Intel announces the availability the Intel Building Management Platform to help small- and medium-size buildings become smart and connected. GE announced new products, acquisitions and partner programs to enable further adoption of Predix™, the operating system for the Industrial Internet.

Source: GE research, the Computer History Museum (www.computerhistory.org).

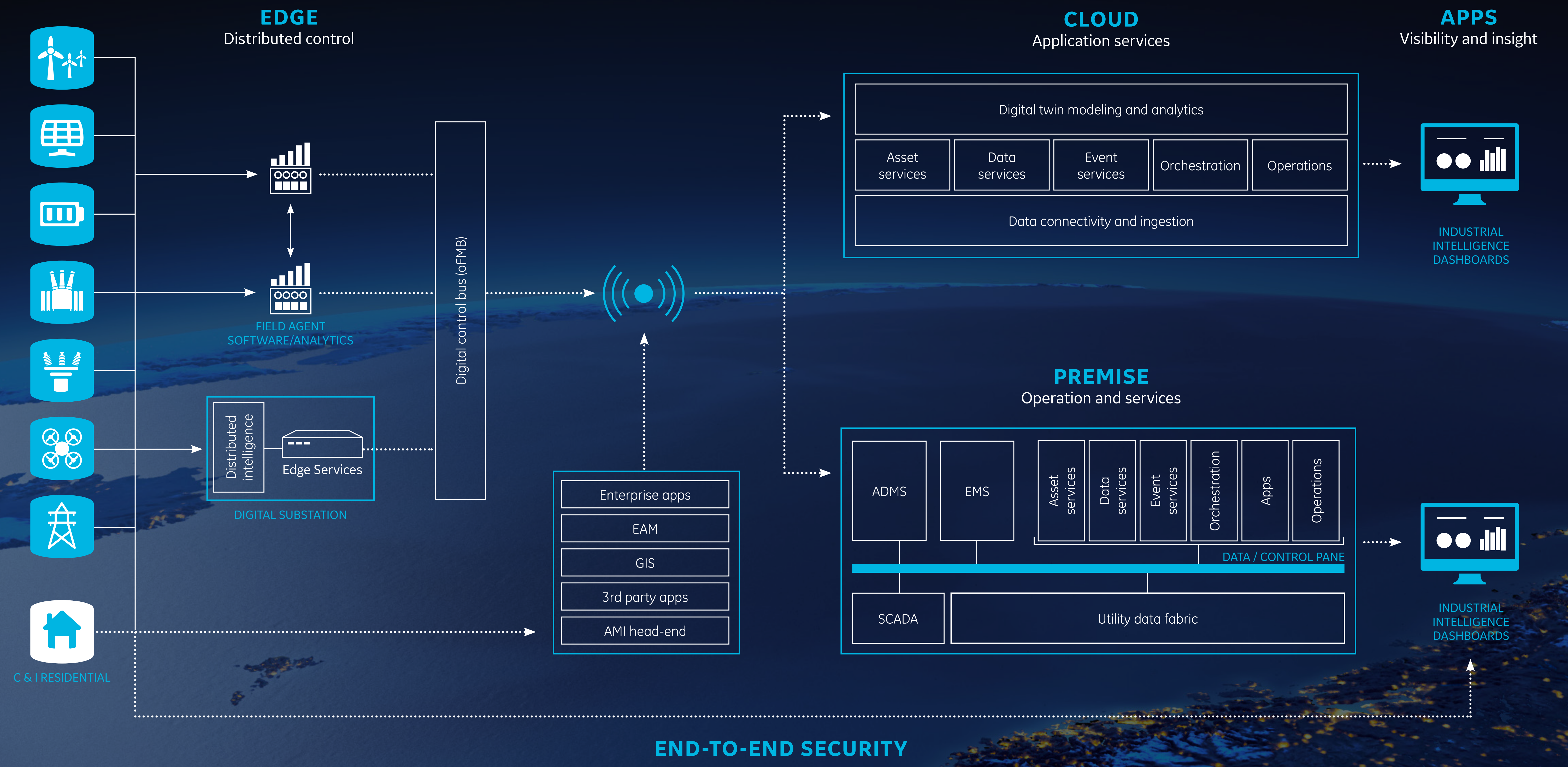
These digital tools have taken advantage of every benefit provided by Moore's law to steadily improve the intelligence that technology providers put into their machines. For example, in the last decade alone, the computational power of a GE Wind turbine controller has grown 15X, taking advantage of the rapid decline of the cost of computation to deliver a rich new portfolio of features that improve the turbine's energy capture as well as its ability to support the grid with advanced functions, including voltage regulation, frequency control, synthetic inertial response and black start functions, to name a few. Over the same time period, a standard substation controller computational capability has grown 30X, allowing for the deployment of advanced protection functionality and remote monitoring, diagnostics and prognostics capabilities. And the computational burden of a standard EMS system has grown by over 3X in the last decade, owing to a larger number of assets under control as distributed energy resources become more common, along with a richer expectation for contingency analyses that prepare the grid for possible faults throughout the network.

And then of course there is the Internet. In the 1990s and 2000s the Internet took off, first targeted at commercial applications, and then later oriented towards the interconnection of things. By 2010, improvements in information technologies enabled the Internet of Things (IoT) to be applied to industrial machinery, leading to the creation of the Industrial Internet. Fueled by technology advances including falling computing prices, the miniaturization of computers, increasing bandwidth, and the emergence of cloud computing, a new paradigm in industrial intelligence was born. In 2011, GE announced its commitment to a $1 billion investment in industrial software and analytics over a three-year period, and in 2013, GE released Predix™, the first software platform for the Industrial Internet. The momentum behind the Industrial Internet is explosive; over 12.5 billion devices are connected to the Internet today, and Cisco estimates that there will be 50 billion connected devices by 2020. The potential for this new resource is enormous, ranging from big data analytics that can look at fleets of equipment to identify more efficient and higher performance ways to operate assets in the field, to the hosting of OT systems for customers looking to simplify their operations, to the provision of high performance computing power needed to solve large scale system optimization problems in real time for business applications, to name just a few.

While the industrial Internet is undoubtedly an enabler for these new capabilities, it is only a part of the digital ecosystem needed to drive transformational outcomes. Realizing true transformation will require coordinating intelligent actions throughout the digital fabric of infrastructure, including intelligence at the edge that sits on physical assets, intelligence in control centers and operating rooms that manage systems, and engaging this new cloud resource and the opportunities it brings. See Figure 2.

The opportunities for digital technologies to transform the electricity infrastructure are many, but this paper will focus on two outcomes that can help utilities reduce their carbon footprint while at the same time improving their economic returns: improving their ability to incorporate higher levels of renewable energy resources, and improving the utilization of their infrastructure, and thus allowing for the deferral of further infrastructure build-out until it is truly necessary.

Figure 2: Digital grid architecture, powered by Predix™



ENABLING MORE RENEWABLES

Several studies have been performed to identify tools that can help realize the renewable energy resource adoption targets set by governments and corporations around the world.[2] While each system and region has unique characteristics, the findings of these diverse studies share the same themes. Key elements of a strategy to economically adopt a high level of variable renewable generation resources such as wind and solar energy include:

- Utilizing "smart" renewables with grid support functions such as voltage regulation, frequency support, curtailment, down reserves, synthetic inertia and black start.
- Incorporating the use of renewable energy resource forecasting in the tools used to plan and operate generation resources, especially unit commitment and economic dispatch in the transmission Energy Management System (EMS).
- Broadening the balancing areas over larger regions and improving inter-area coordination, to allow better resource averaging to reduce the impact of local power variability.
- Upgrading the conventional thermal generation fleet to have more flexibility, including larger turndown for partial power operation, faster ramp-rates, and improving fast start and stop capability.
- Using energy storage and demand response to compensate for wind and solar variability, with an important function to provide bridge power while conventional generation is started.
- Taking advantage of the flexibility available in distributed energy resources (DERs) to provide local compensation for power and voltage variability, coordinated by controls platforms such as a Distributed Energy Resource Management System (DERMS), or a Microgrid controller.

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[2] For full versions of all GE Energy Consulting studies in this area see https://ge-energy.postclickmarketing.com/RenewableIntegration

GE has made considerable investments in technology enablers for all of these tools, including the development of advanced grid support functions in our wind and solar energy offerings, the development of flexibility offerings in our gas turbine and reciprocating engines, the ability of utility operations platforms such as EMS, MMS, DMS, DERMS and microgrid controllers to better see and coordinate renewable resources, and the launch of emerging variability compensation tools such as energy storage, hybrid-electric gas turbines, and demand response systems. All of these tools call for changes in the way power grids are operated, and all are enabled by the digital fabric that extends from the controls on generation and grid assets, up through utility operations. Many of these will be made even more powerful with the emergence of deep, broad and fast intelligence that can be provided by the cloud.

By enabling larger shares of these resources, the overall mix of generation resources on the grid will become cleaner over time and pass fuel savings on to end customers.

In a recent study of the Hawaiian islands performed by GE Energy Consulting, it was found that the islands of Maui and Oahu could absorb greater than 35 percent of variable renewable generation while at the same time delivering a lower cost of energy to end users than what they pay today. The study found that as the renewable energy penetration level approaches 50 percent, the amount of diesel used by the thermal fleet on the islands would reduce by over 33 percent, delivering a reduction of 2 million metric tonnes of CO_2, which is 33 percent of electric power sector emissions on Oahu and Maui.

In another recent study, it was found that by ramping up wind generation across Canada from 5 percent to 35 percent, there is the potential to reduce emissions in the country by up to 32 million metric tons of CO_2.

ENHANCING THE UTILIZATION OF T&D INFRASTRUCTURE

Investments in upgrading and expanding T&D infrastructure around the world are driven by many different motivations. In mature grids, while total energy demand is either flat or growing slowly, the generation mix is changing at an accelerating pace, with renewable energy resources coming online at a furious pace. Many of these grids have problems with transmission congestion, where constraints in power flow capacity are limiting consumer access to low cost electricity and costing rate payers billions of dollars every year. Congestion also makes it more costly for new renewable energy resources to connect to the grid, requiring either transmission upgrades or an acceptance of high curtailment rates. Hence grid investments in mature economies continue to grow.

In emerging markets, where demand is growing more quickly, both generation and power delivery infrastructure are being expanded to keep up. In China, a strong grid with HVAC and HVDC paths is being built up to support the industrial appetite of the country. In India, the power grid is now being run as one large synchronous interconnection, merging both HVAC and HVDC paths to support a demand that hovers near grid capacity. In both of these countries, the adoption of renewable energy is a national priority and accelerating, driving further investment in grid infrastructure.

In both mature and emerging economies, the buildout of wires infrastructure is essential to support these diverse needs. A broad set of new tools can help extract more performance from the infrastructure that is already in the ground, and can raise the productivity of new infrastructure yet to be built. These alternative “non-wires” tools come in many forms, and in many cases offer a faster and more economical way to get at least part of the grid capacity growth that is needed by pushing the use of infrastructure closer to its full capacity. In so doing, they can help improve the ability for new renewable energy resources to connect to currently saturated grids, reduce curtailment in existing renewable resources connected to congested systems, and defer wires infrastructure buildout for many years, thereby also deferring the carbon footprint associated with the materials and installation of these projects. These non-wires tools can be categorized by the manner in which they improve utilization:

- Tools that reduce uncertainty associated with transmission limits, such as Phasor Measurement Units, which can help reduce the need for state estimation to determine the system stability margin, or temperature and wind sensors, which can be used to accurately rate the transmission capacity of wires, compared to the estimated or worst-case temperatures used to rate lines in many utilities today.
- Tools that reduce conservatism in the operation of the grid, such as Special Protection Schemes that can be used to allow a more aggressive operation of transmission lines, by ensuring that upon a fault a quick control action such as load shedding or generation tripping can maintain stable grid operation.
- Tools that move, or reshape, the limits in grid infrastructure, such as FACTS devices which can be used to temporarily shift the stability limits of transmission lines, or to change the impedance characteristics of one or several transmission lines to optimize the distribution of power flow over a network.
- Tools that reshape the demand profile, such as energy storage or demand response, which can be controlled in distribution systems to reduce the peak demand seen by the transmission system.

As mentioned before, every system is different, and the amount of transmission capacity that can be unlocked using these tools will vary from case to case. Reported industry benefits range from 10-20 percent improvements using tools such as dynamic transmission line ratings and FACTS devices, to unique situations where transmission capacity was more than doubled by using Special Protection Schemes.

The environmental benefits of applying these tools vary greatly as well, depending on the nature of the outcome they were intended to achieve. In cases where transmission capacity was boosted to make room for new renewable energy resources, the benefits correlate directly to the change of the fuel mix in the region served by the project. In cases where congestion is reduced and the deployment of new transmission wires can be deferred, the benefit correlates to the avoidance of raw materials and construction associated with the avoided project.

This can be meaningful; an example from a World Bank report on the impact of T&D projects on greenhouse gas (GHG) emissions shared the environmental footprint of a transmission line.[3] Each ton of aluminum has an equivalent CO_2 footprint of 14.5 tons, and each ton of steel has an equivalent CO_2 footprint of 1.6 tons, with the result that each kilometer of transmission has a total equivalent CO_2 footprint of over 28 tons. This does not include the land clearing and construction emissions footprint, which can be considerable as well.

GE has made substantial investments in this class of tools as well, and through the Energy Consulting division has the system engineering expertise to help customers architect solutions that help improve their grid capacity using this class of tools. Again, solutions built using this toolset take advantage of the digital fabric in the grid, carefully orchestrating decisions made by controls at the edge with supervisory systems in utility operations centers, to safely take the power flow over the grid network closer to limits.

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[3] World Bank. (November 2010). Impacts of Transmission and Distribution Projects on Greenhouse Gas Emissions. Washington DC.

ENVIRONMENTAL POTENTIAL OF THE DIGITAL GRID

The ability of T&D technologies to deliver positive economic and environmental outcomes is not new. In fact, a 2010 report by the Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy provided an assessment of several mechanisms by which digital grid technologies can reduce energy use and carbon impacts associated with electricity generation and delivery[4]. To the extent possible, the associated reductions in electricity and CO_2 emissions were quantified to illustrate the benefits inherent in the digital grid's potential contribution to the nation's goal of mitigating climate change from reducing the carbon footprint of the electric power system. Environmental impacts to air and water quality and land use were not considered, nor were impacts on end users that rely upon natural gas as their energy source.

The reductions in electric utility electricity and CO_2 emissions in 2030 attributable to these mechanisms by direct and indirect effect are shown. See Figure 3. The direct reductions were calculated for the mechanisms that affected electricity and CO_2 emissions directly through implementation of the smart grid technologies. Indirect reductions are derived by translating the estimated cost savings in energy and/or capacity into their energy and carbon equivalents through purchase of additional cost-effective energy efficiency. This can represent a policy decision to reinvest the savings to purchase additional more cost effective energy efficiency and renewable resources.

The importance of these reduction estimates is in their combined effect. While several of the mechanisms are estimated to have small or negligible impacts, five of the mechanisms could potentially provide reductions of over 1 percent. Moreover, the combined effect of the direct mechanisms is 12 percent, and the indirect mechanisms total 6 percent of energy and emissions for the U.S. electricity sector. These correspond to 5 and 2 percent of the U.S. total energy consumption

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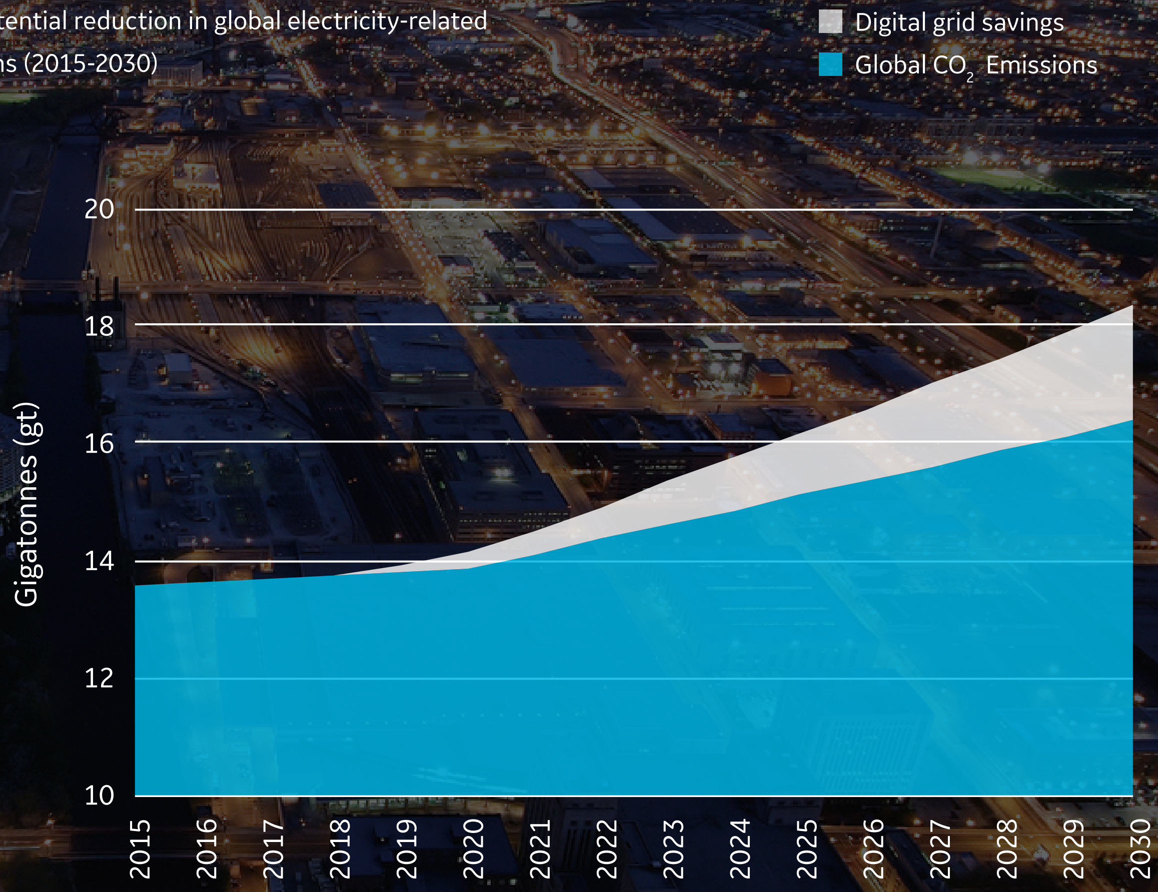
[4] Pacific Northwest National Laboratory. (January 2010). *Smart Grid: Estimation of the CO_2 Benefits.*

and energy-related CO_2 emissions for all sectors (including electricity). The magnitude of these reductions suggests that, while digital grid technologies will not be the primary mechanism for achieving aggressive national goals for energy and carbon savings, they can provide a very substantial contribution towards meeting them.

As a crude exercise, scaling PNNL's estimate of a 12 percent reduction in electricity consumption in 2030 globally, produces a significant environmental benefit, reducing global carbon dioxide emissions in 2030 by 2 billion metric tonnes per year. This is roughly equivalent to taking half the world's passenger cars today off the road.

Figure 3: Potential reduction in global electricity-related CO_2 emissions (2015-2030)



Source: GE and Pacific Northwest National Laboratory, January 2010

CONCLUSION

This is an important time for the energy industry, as the world accelerates its embrace of clean and renewable energy resources to power its development and growth. In the middle of all of this transformation lies the grid, the true enabler that receives this clean energy and routes it to end users. The nature of the grid has already started to change, moving away from a sole bulk transport mission to a broader mission that adds a strong role in balancing power across regions as renewable energy production shifts geographically and temporally throughout the day. How the grid evolves, both physically and digitally, will determine how economical the transformation to these cleaner energy resources is, and will therefore be a factor in the speed at which they are adopted.

Connecting the coming new renewable energy resources to the grid will require significant investments in T&D infrastructure. To make these investments economical, it is imperative that decision makers give thoughtful consideration to the way that the grid is operated. By doing so, they will maximize the flexibility of installed and new assets to compensate for the variability of these resources.

Moreover, these investments should cast a wide net in looking at the tools to be deployed for realizing expansion of the power delivery capacity. Non-wires alternatives, coupled with a deeper and faster intelligence governing the operation of the grid, can allow significant growth in capacity to come from within the infrastructure already deployed, as well as to help new infrastructure be sized with an expectation of higher performance.

All of the tools described in this paper call for a smarter, more aggressive operation of the grid that pushes closer to limits by taking advantage of a much better understanding of the current state of the network. These tools do not reside in singular locations of the grid; instead they are stitched together into solutions that deploy the right intelligence throughout all levels of the grid. The intelligent fabric that extends from control systems on generation assets, through utility operations centers, and into a new and powerful cloud resource is the digital grid, and it is an essential part of the energy ecosystem of the future.

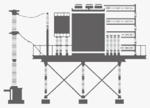
GE ECOMAGINATION

As a 125-year old technology company, GE has always believed in progress, investing, and taking risks to improve technology and build a brighter future for our customers and the world around us. From the invention of the first practical incandescent light bulb to building America's first central power station, the GE tradition of life-changing innovation is unparalleled.

Twelve years ago, with a vision to make a global impact on environmental outcomes and economic growth, GE decided to redefine what it means to be environmentally focused. So in 2005 we launched GE Ecomagination (http://ecomagination.com) to provide advanced technology solutions that improve resource efficiency and economics for our customers, and improve efficiency in our own operations. See Figure 4. The GE Ecomagination portfolio is comprised of 74 GE products and solutions that deliver significant improvements in operational and environmental performance. Spanning the GE portfolio and including hardware and software applications, select products – among them several grid solutions technologies– are included in the portfolio after businesses demonstrate the solutions' economic and environmental benefits compared to a baseline.

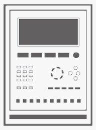
GE ENERGY CONNECTIONS

GE is as committed to grid technologies as we are to making an environmental impact. GE Energy Connections (http://geenergyconnections.com) is GE's electrification, grid and controls business, operating in more than 150 countries with 45,000 employees. Our breadth and depth enables our customers to connect power to more people. GE Energy Connections' Grid Solutions business has helped 90 percent of the world's transmission utilities deliver power reliably and efficiently to their customers. GE's grid solutions include power systems consulting, power electronics, high voltage equipment, automation and protection, software solutions, and projects and services.



Power Electronics
- High Voltage DC Systems
- Flexible AC Transmission Systems
- Industrial DC Substations
- Energy Storage

High Voltage Equipment
- Transformers
- Gas Insulated Substations
- Air Insulated Substations
- Capacitors and Reactors



Automation & Protection
- Protection and Control
- Substation Automation
- Communications and Metering
- Monitoring and Diagnostics

Software Solutions
- Distribution and Outage Management
- Energy Management Systems
- Geospatial and Mobile Solutions
- Gas and Pipeline Management

Projects & Services
- Turnkey Projects and Consulting
- Electrical Balance of Plant
- High Voltage Substations
- Maintenance and Asset Management

Figure 4: Ecomagination Timeline

2005–2007 FIRST GENERATION GOALS

In 2005, GE launched Ecomagination, its commitment and strategy to solve the world's biggest energy and environmental challenges.

GE commits to:

1. Doubling its investment in clean research and development (R&D) from $700 million/year to $1.5 billion/year by 2010.
2. Growing revenues from Ecomagination products to at least $20 billion.
3. Reducing its greenhouse gas (GHG) emissions by at least 1% by 2012.
4. Reducing its global water use by 20% between 2006 and 2012.

2010 JOURNEY

1. $7 billion invested in clean R&D.
2. $85 billion in Ecomagination product revenue.
3. 22% reduction in GE's GHG emissions from the 2004 baseline.
4. 30% reduction in water use from the 2006 baseline.

2014 SUCCESS AND SECOND GENERATION GOALS

1. $15 billion invested in clean R&D.
2. $200 billion in Ecomagination product revenue.
3. 31% reduction in GE's GHG emissions from the 2004 baseline.
4. 42% reduction in GE's water use from the 2006 baseline.

2016 PROGRESS SINCE LAUNCH

1. $20 billion cumulative investment in clean R&D.
2. $270 billion cumulative revenue from Ecomagination products.
3. 74 Ecomagination qualified solutions.

GE's Ecomatination initiative, launched in 2005, led to the development of ultra-efficient technologies that have provided resource productivity improvements across industries. Looking ahead, Ecomagination and the Industrial Internet promise to unleash accelerated resource productivity improvements.

2005 2007 2009 2011 2013 2015 2017

2005
GE creates the Ecomagination product review scorecard, which quantifies a product's or solution's environmental benefits.

2005
GE surpasses 5,000 installations for its 1.5-megawatt wind turbine.

2006
GE increases its annual investment in clean R&D from $700 to $900 million and expands research on renewable energy, clean coal, carbon captures, water, and energy efficiency.

2006
GE launches Ecomagination in China, nearly 100 years since GE first began working in the country.

2007
GE Transportation's partner United Group Rail delivers ten Evolution Series locomotives to Rio Tinto Iron Ore, bringing advanced locomotive technology to an energy-intensive industry.

2007
GEnx becomes the fastest-selling engine in aviation history and offers up to 15% better fuel consumption compared to GE's CF6 engine. Emirates, an airline based in Dubai, is among those GE customers that have chosen GEnx engines to power their fleets.

2007
GE Energy's Jenbacher gas engines power Japan's largest wood-based gas-to-energy plant.

$1.5 BILLION

2009
GE surpasses its clean tech R&D goal of $1.5 billion one year early.

2010
GE commits to buying 25,000 alternative fuel vehicles by 2015 to use in its fleets and fleet-services business in 2010.

2010
Ecomagination software solution Movement Planner™ makes it possible for trains to move more freight faster and more efficiently on existing rail lines.

2010
Proficy™, a software platform for measuring and managing the efficiency of manufacturing operations, is included in the Ecomaginaton portfolio.

2011
Ecomagination opens GE to outside innovation through the Ecomagination Challenge, collaborating with venture capital firms to help bring exciting new energy technologies to the world.

2012
Ecomagination Nation (a global GE power and water initiative designed to protect the environment by encouraging employees to take action) gains increasing momentum within GE.

2013
Ecomagination launches Brilliant™ Wind, a renewable energy system comprised of a wind turbine, battery, and software. The system harnesses the power of the Industrial Internet and reaps the benefits of energy storage without the high costs.

2014
GE opens the Ecomagination center in Masdar City, United Arab Emirates.

2014
GE provides its ZeeWeed™ 1500 ultrafiltration system to the Santa Eufemia water treatment plant in Northern Portugal.

2014
San Diego becomes the first city to install LightGrid™, GE's wireless lighting control system.

$15 BILLION

2014
GE invests a cumulative $15 billion in clean R&D.

2014
GE's Industrial Internet solutions are added to the Ecomagination portfolio.

2015
Celebrated 10 Year Ecomagination Anniversary with new industrial partners.

2015
Digital Wind Farm has the potential to boost energy production up to 20%.

2016
Utility Scale Silicon Carbide Solar Inverter is 99% efficient.

2016
Block Island – first US offshore wind project.

2016
Fortune Magazine names GE Ecomagination number 3 in its Change the World list.

2016
First Ecomagination hackathon with California State University to reduce energy and water waste.

2017
GE wins Zayed Future Energy Prize.

Source: GE