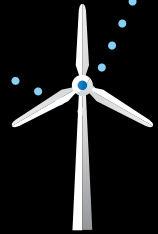


Ecomagination



# THE RENEWABLE ENERGY ERA

GE, Ecomagination and the Global Energy Transformation  
By Brandon Owens





## ACKNOWLEDGEMENTS

I would like to thank my colleagues at GE Renewable Energy, Current, GE Energy Management, GE Energy Consulting, GE Energy Financial Services, and GE Ventures for their support and collaboration in the development of this report. I would also like to thank Doug Arent and the research team at the Joint Institute for Strategic Energy Analysis (JISEA) for their continued partnership and research support. Insights from JISEA's GE-sponsored report "Renewable Electricity: Insights for the Coming Decade" were an important component of this report.

## AUTHOR BIOGRAPHY

### **Brandon Owens, Ecomagination Strategy & Analytics Director**

Brandon Owens is an economist, energy specialist, technology researcher, and writer. His research has been published in industry-leading journals such as *INFORMS*, *Public Utilities Fortnightly*, *Energy Policy*, and *Research Evaluation*. An author, keynote speaker, and expert witness, Mr. Owens has been cited in periodicals such as the *New York Times* and *USA Today*.

The author of GE's white papers "The Power of Tomorrow," "The Rise of Distributed Power," and "Digital Resource Productivity," Mr. Owens is currently the director of Ecomagination Strategy & Analysis at GE, where he helps guide the strategic direction of GE's flagship environmental sustainability initiative. Prior to this role, he was the Manager of Strategy & Analytics within GE Energy's Global Strategy & Planning group.

Before joining GE, Mr. Owens was Global Power Director at IHS Cambridge Energy Research Associates (IHS CERA). He also founded and led the Renewable Power consulting practice at Platts Research & Consulting. Earlier in his career, Brandon served as Senior Analyst for the National Renewable Energy Laboratory (NREL). Mr. Owens holds an MS in Mineral Economics from the Colorado School of Mines and a BA in Mathematics and Economics from the University of Colorado Boulder.

## CONTENTS

|                                        |           |
|----------------------------------------|-----------|
| <b>Executive Summary</b>               | <b>2</b>  |
| <b>I. Introduction</b>                 | <b>10</b> |
| From Transition to Transformation      | 10        |
| Environmental Benefits                 | 12        |
| The Path Forward                       | 13        |
| <b>II. Renewable Energy Innovation</b> | <b>16</b> |
| <b>Wind Power</b>                      | <b>16</b> |
| Brilliant Wind Turbine                 | 20        |
| Digital Wind Power                     | 20        |
| Wind Power Today                       | 22        |
| Next Generation Wind Power             | 22        |
| <b>Solar Power</b>                     | <b>26</b> |
| Solar as a Service                     | 27        |
| Next Generation Solar                  | 28        |
| Concentrating Solar Power              | 30        |
| <b>Hydropower</b>                      | <b>31</b> |
| <b>Biopower</b>                        | <b>32</b> |
| <b>Geothermal</b>                      | <b>33</b> |
| <b>Ocean</b>                           | <b>33</b> |
| <b>III. Renewable Energy Economics</b> | <b>35</b> |
| Renewable Energy Cost Competitiveness  | 35        |
| Innovation-Led Cost Declines           | 36        |
| <b>IV. Renewable Energy Outlook</b>    | <b>39</b> |
| <b>V. Enabling the Transition</b>      | <b>44</b> |
| Grid Integration                       | 44        |
| Grid-Friendly Renewables               | 45        |
| Energy Storage                         | 45        |
| Digital Renewable Energy               | 45        |
| Renewable Energy Commitments           | 46        |
| Financial Innovations                  | 47        |
| <b>VI. Transforming Tomorrow</b>       | <b>48</b> |



# EXECUTIVE SUMMARY

The renewable energy era has begun. The pace of growth of renewable energy technologies—hydropower, wind, solar, geothermal, biopower, and emerging renewables—has accelerated in the last decade.<sup>1</sup> Since 2005, 870 gigawatts (GW) of renewable energy capacity have been added to the global electric power system. According to the International Renewable Energy Agency (IRENA), in 2014, 37 GW of hydropower, 51 GW of wind power, and 40 GW of solar power were installed.<sup>2</sup> Today, when a new power plant is built somewhere in the world, it is just as likely to be renewable as it is fossil fuel or nuclear. This isn't just a trend—it's the start of a decades-long transformation of the global power system.

The renewable energy era is well aligned with GE's commitment to renewable energy. Through the Ecomagination strategy, GE is deeply committed to developing and deploying technologies that maximize resource efficiency, economics, and environmental performance. Since its inception in 2005, the GE technologies and solutions within the Ecomagination portfolio have generated \$200 billion in revenue. GE has maintained its commitment to efficient resource solutions by investing \$15 billion in cleaner research and development (R&D) over this period and will invest an incremental \$10 billion by 2020. Renewable energy lies at the center of Ecomagination. Debora Frodl, Ecomagination's Global Executive Director, puts GE's commitment to renewables in perspective: "Creating cleaner technologies like renewable energy to help our customers transform their industries while driving greater resource efficiency, economics, and environmental performance—that's what GE Ecomagination is all about."

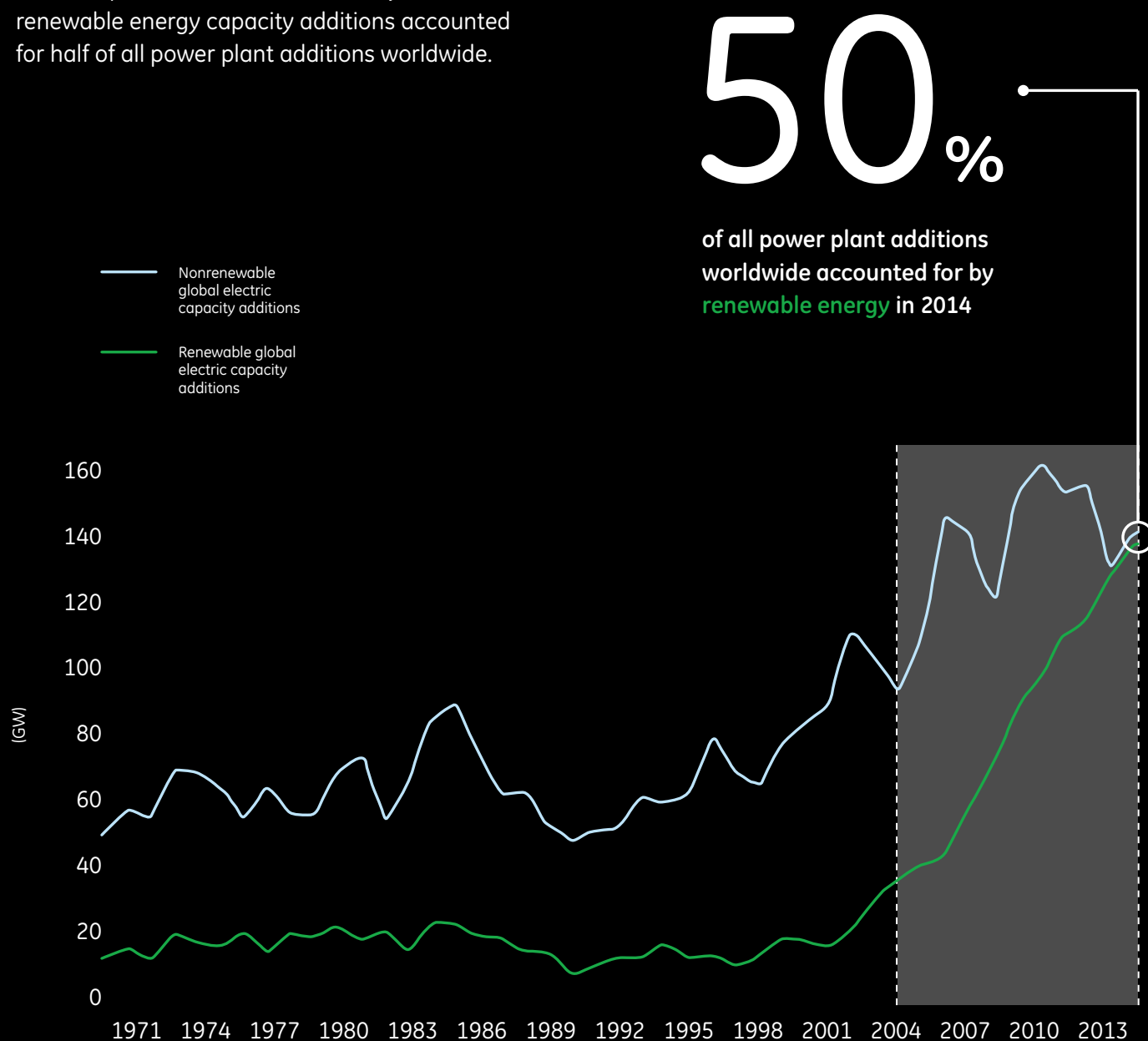
*Creating cleaner technologies like renewable energy to help our customers transform their industries while driving greater resource efficiency, economics, and environmental performance—that's what GE Ecomagination is all about.*

*—Debora Frodl, GE Ecomagination Global Executive Director*

GE has a long history developing renewable energy technologies, starting with its role providing power equipment for early hydropower plants and continuing to our involvement in the world's first megawatt-scale wind turbine in 1941.<sup>3</sup> GE has also been involved in solar energy research for decades, with scientists and engineers around the world at our Global Research centers exploring every aspect of the solar energy value chain. From GE Renewable Energy and GE Power Conversion to GE's new start-up Current, GE's renewable energy portfolio is both broad and deep. With the addition of Alstom, GE now offers one of the world's most diverse portfolio of renewable energy technologies, products, and services. When combined with GE's built-in capability to innovate and synthesize across global industries, the diversity of offerings and expertise within GE's renewable energy universe are vast.

Figure 1. The renewable energy era has begun: Renewable and nonrenewable global electric capacity additions (1970–2014)

Renewable energy has experienced a surge of development in the last decade. By 2014, renewable energy capacity additions accounted for half of all power plant additions worldwide.



Source: GE, International Renewable Energy Agency (IRENA).



## current

powered by GE

Current, powered by GE, is a digital power service company built to transform the way the world uses energy. Current brings innovation into one place by combining GE's capabilities in LED, energy storage, solar, distributed generation, electric vehicle infrastructure, and financial solution into a single sustainable energy ecosystem powered by GE's Industrial Internet platform Predix. The Current technology ecosystem will help to save customers an estimated 10 to 20 percent on their energy bills and help utilities better manage the load on the energy network. GE is working with businesses such as Walgreens, Simon Property Group, Hilton Worldwide, and Intel to meet their energy needs and increase control and independence, all while saving costs.

Data from global electricity markets highlight the magnitude of renewable energy's presence on the global power scene. In 2014, generation from renewable energy sources added up to nearly 5,500 terawatt hours (TWh). Renewables have now edged out natural gas as the second largest source of electricity generation, second only to coal.<sup>4</sup> The current boom in renewable energy over the last decade now places renewables alongside natural gas as a leading fuel of the future. Renewables are an important addition to the diverse international electricity generation portfolio.

New investments in renewable power are also outpacing investment in additional fossil fuel capacity. Global new investment in renewable energy, excluding large hydro, was \$270 billion in 2014.<sup>5</sup> That represents a 17 percent increase from 2013. Investments in renewable energy were evenly split between developed and developing countries. Total investment in fossil fuel generation capacity was \$289 billion. However, many of these

investments were made to replace existing power plants that were being retired. Investments for net fossil fuel capacity additions were \$132 billion. This means that investment in renewable energy capacity additions far outpaced investments in net capacity additions for fossil fuel plants. In fact, the European Bank for Reconstruction and Development has reported more investments in renewable energy than in thermal power generation for the first time.<sup>6</sup>

The strong growth of renewable energy over the last decade and the increasingly important role that renewables are playing in electric power markets around the world, represent the start of a renewable energy transition that will lead to an increasingly diversified and reliable power system that has a lower environmental impact. GE estimates that the quantity of non-hydro renewable electricity today is already reducing global electric sector carbon dioxide (CO<sub>2</sub>) emissions by 8 percent.<sup>7</sup> Further, increases in renewable energy will also reduce the water footprint of electricity generation around the world, at a time when local and global water scarcity has become an economic and environmental challenge.

### GE Power Conversion

GE's Power Conversion business applies the science and systems of power conversion to help drive the electric transformation of the world's energy infrastructure. Designing and delivering advanced motor, drive and control technologies that evolve today's industrial processes for a cleaner, more productive future. Power Conversion serves specialized sectors such as energy, marine, industry and all related services. Transforming energy to optimize customer processes is our mission. Electrical energy into mechanical energy by a motor, mechanical energy into electrical energy by a generator or adjusting frequency and current through a converter or an inverter.

## Figure 2. GE's diverse renewable energy portfolio

With the addition of Alstom to our portfolio, GE now has one of the most diversified sets of renewable energy offerings in the world spanning the range of technologies, services, and investments.

# GE is a world leader in renewable energy offerings.



Ecomagination

### RESEARCH & DEVELOPMENT

- GE Global Research
- Ecomagination sustainable energy research portfolio

### TECHNOLOGIES

- Onshore and offshore wind power systems
- Alstom hydropower, geothermal, biomass, and concentrating solar power solutions
- GE Energy Management solar inverters and electrical balance of system (BOS)
- Alstom tidal steam turbines
- Current distributed energy and storage solutions
- GE Power Conversion electrical equipment (induction generators, drives)

### SOFTWARE & SERVICES

- PowerUp
- Brilliant Wind Turbine
- Digital Wind Farm
- Alstom Hydro Services
- SunIQ plant control system
- Alstom Geothermal, Biomass, and Solar Services

### DEVELOPMENT & INVESTMENT

- GE Energy Financial Services renewable energy project portfolio
- GE Ventures renewable energy start-up investment portfolio

### PARTNERSHIPS

- Ecomagination commercial partnerships



### Wind Power Innovation and the GE Store

GE invested over \$2 billion over the last decade in wind power R&D and used the GE Store to accelerate wind turbine innovation. The GE Store is GE's term for the synergistic benefits created by the company's ability to share insights, innovation, culture, and processes across its broad range of global industrial businesses. The GE Store is a place where GE business can come for technologies, product development, and services that no one else can provide.

In the case of wind power, the GE Store has enabled GE to accelerate wind turbine innovation over the last decade. GE leveraged GE Global Research—an army of more than 3,000 scientists, engineers, and researchers working together to deliver technical breakthroughs to GE customers—to apply technologies and insights from other fields to make wind turbines better. GE now uses imaging algorithms designed for the health-care system in sensors embedded in our wind turbine blades, gearbox innovations from GE Transportation, control systems from GE Aviation, and computational fluid dynamics models from gas turbines within GE Power.

A confluence of factors is driving the renewable energy transition. First, growth in global electricity demand has fueled the rise of all power generation technologies. GE estimates that global electricity generation rose from 16,800 to 21,900 TWh between 2005 and 2014. That's an increase of over 5,000 TWh; nearly 2,000 GW of new sources of electricity have been installed to meet this growing demand. Second, the rising threat of climate change, the desire for increased domestic energy security, and enhanced economic development have prompted policymakers to implement an increasing number

of renewable power support policies across the globe. These policies have been successful in encouraging the adoption of renewable power over the last decade.<sup>8</sup>

Third, and most importantly, as a result of technology innovation, renewable power technologies have become increasingly cost competitive over time and more grid-friendly or compatible with the electric power system. According to Bloomberg New Energy Finance (BNEF), the levelized cost of electricity (LCOE) for onshore wind power has declined by 15 percent since 2009, which has enabled wind power to be the least-cost source of electricity generation in many jurisdictions around the world. The largest cost reductions have come from solar photovoltaic (PV) technology, which has experienced a 53 percent decline in costs since 2009. New technologies that incorporate energy storage to reduce the impact of variability from wind and solar PV technologies, as well as the addition of digital technologies that ensure the renewable power system are fully optimized, will continue to push down the cost of renewable energy.

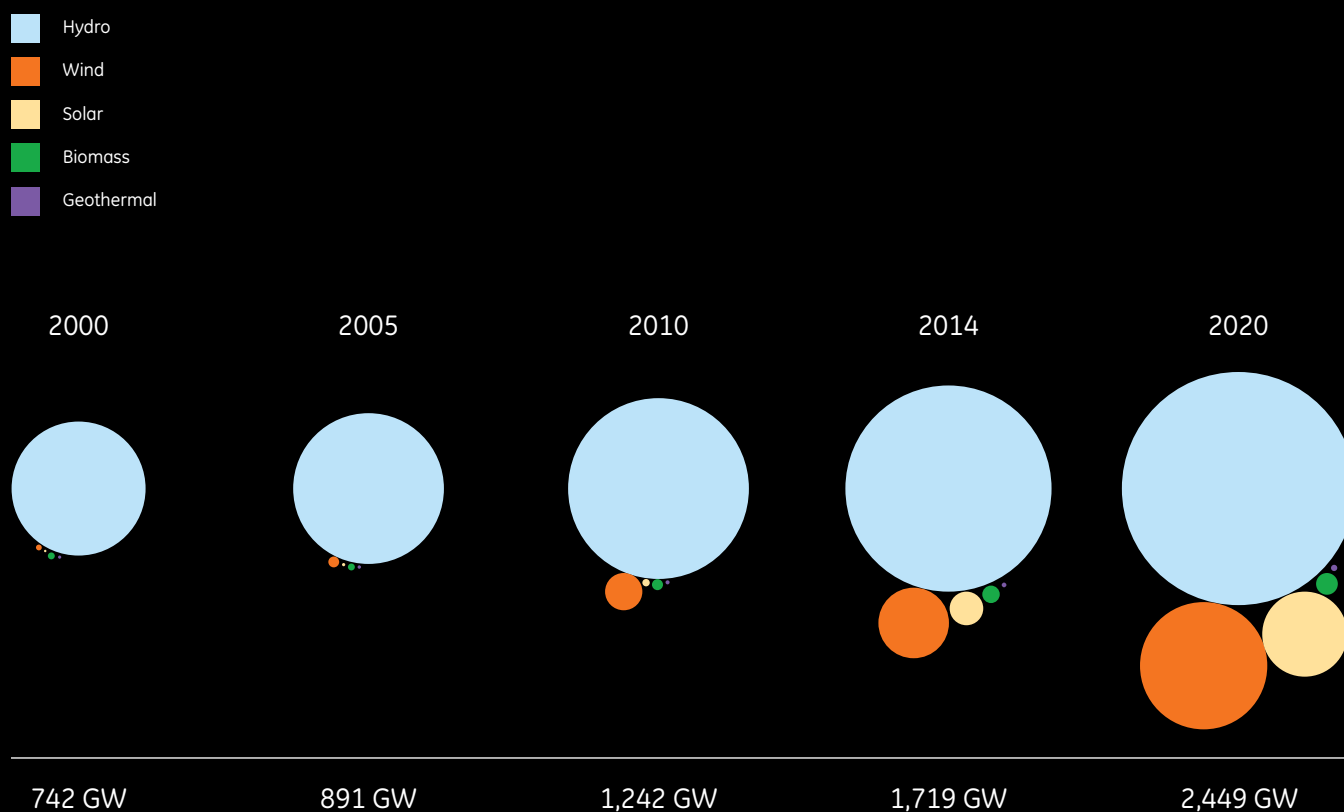
Looking ahead, the combination of business innovation and smart renewable energy policies will continue to drive large amounts of renewable energy investment, capacity, and generation. GE estimates that another 730 GW of renewable energy capacity will be added between 2015 and 2020. Renewable energy capacity additions will account for over 50 percent of total global electric power capacity additions between 2015 and 2020. As with the last decade, hydropower, wind, and solar PV are expected to account for the bulk of these additions. Carbon dioxide emissions from electricity generation will be up to 13 percent lower in 2020 than they would otherwise be without non-hydro renewable power technologies in the global electricity portfolio.



Figure 3. Green growth: Renewable energy installed capacity (2000–2020)

After growing from 891 to 1,710 gigawatt (GW) of installed capacity between 2005 and 2014, renewable energy is poised to continue to grow through the end of the decade. By 2020, GE estimates that another 730 GW of renewable energy capacity will be added to the global electric power system.

+730  
GW renewable energy capacity by 2020



Source: GE, International Energy Agency (IEA), International Renewable Energy Agency (IRENA).



However, the path forward contains both challenges and opportunities. First, stakeholders must work together to coordinate and integrate electricity planning, develop rules for market evolution that enable system flexibility, expand access to diverse resources, and improve system operations. In order to accommodate increasing levels of variable renewable energy, both demand- and supply-side technologies within the electric system must become increasingly flexible. Greater levels of deployment and utilization of the existing grid-friendly capabilities of renewables will be required. Technology innovations, like more sophisticated methods of forecasting the wind and sun, and cost-competitive energy storage solutions, will be needed to allow renewables to become more predictable and to better manage variability. And finally, the Industrial Internet must be fully leveraged to enable greater control and coordination across the grid.

Through technology and business model innovation, GE believes that these challenges can be transformed into opportunities. At GE, innovation is driven across the organization and accelerated by GE's commitment to Ecomagination innovations like GE's Digital Wind Farm™ and new Industrial Internet offerings on the horizon that successfully blend the physical and digital in ways that help maximize resource productivity across the global energy system. Furthermore, the integration of technologies in new ways to create integrated hybrid systems offers a promising innovation pathway for renewables. In addition, new financial innovations promise to unlock new sources of capital for renewable energy projects and developers.

Cost-competitive and environmentally sustainable power generation technologies are more than just an aspiration; they are now the reality. Over 100 years ago, GE imagined a world where humankind was able to successfully harness the

sun, wind, and sea. Thanks to continuous technology innovation, this is the world that we live in today. Let's seize this opportunity and work collaboratively to further accelerate renewable energy innovation, build new solutions, and create a sustainable electric power system for the planet, its people, and the world economy.

*Over 100 years ago, GE imagined a world where humankind was able to successfully harness the sun, wind, and sea. Thanks to a century of technology innovation, this is the world that we live in today. Let's seize this opportunity and work collaboratively to further accelerate renewable energy innovation and create a sustainable electric power system for the planet, its people, and the world economy.*





# I. INTRODUCTION

Energy transitions are long-term structural changes in the global energy system. In the last 200 years, the world has undergone two fundamental energy transitions. These changes have encompassed the fuels and technologies employed, the services provided, and the environmental impacts caused by energy production and consumption. The first energy transition occurred in the late nineteenth century, when the world moved from wood to coal power. Wood was the dominant fuel for many decades but was later overtaken by coal. Between 1870 and 1990, energy consumption in the United States shifted from 70 percent wood to 70 percent coal. The next energy transition occurred when coal itself was overtaken by hydrocarbons (oil and natural gas) in the mid-twentieth century. By 1960, 70 percent of US energy consumption was comprised of oil and gas.

The world is now embarking upon another energy transition. This time, the energy system is shifting toward newer, low-carbon sources of supply. Renewable energy fuels and technologies are now being rapidly added to the global energy system. According to the International Renewable Energy Agency (IRENA), since 2005, 860 GW of renewable energy capacity have been added to the global electric power system. In 2014 alone, 37 GW of hydropower, 51 GW of wind power, and 40 GW of solar power were installed. The fact is, when a new power plant is built somewhere in the world today, it is just as likely to be renewable as nonrenewable.

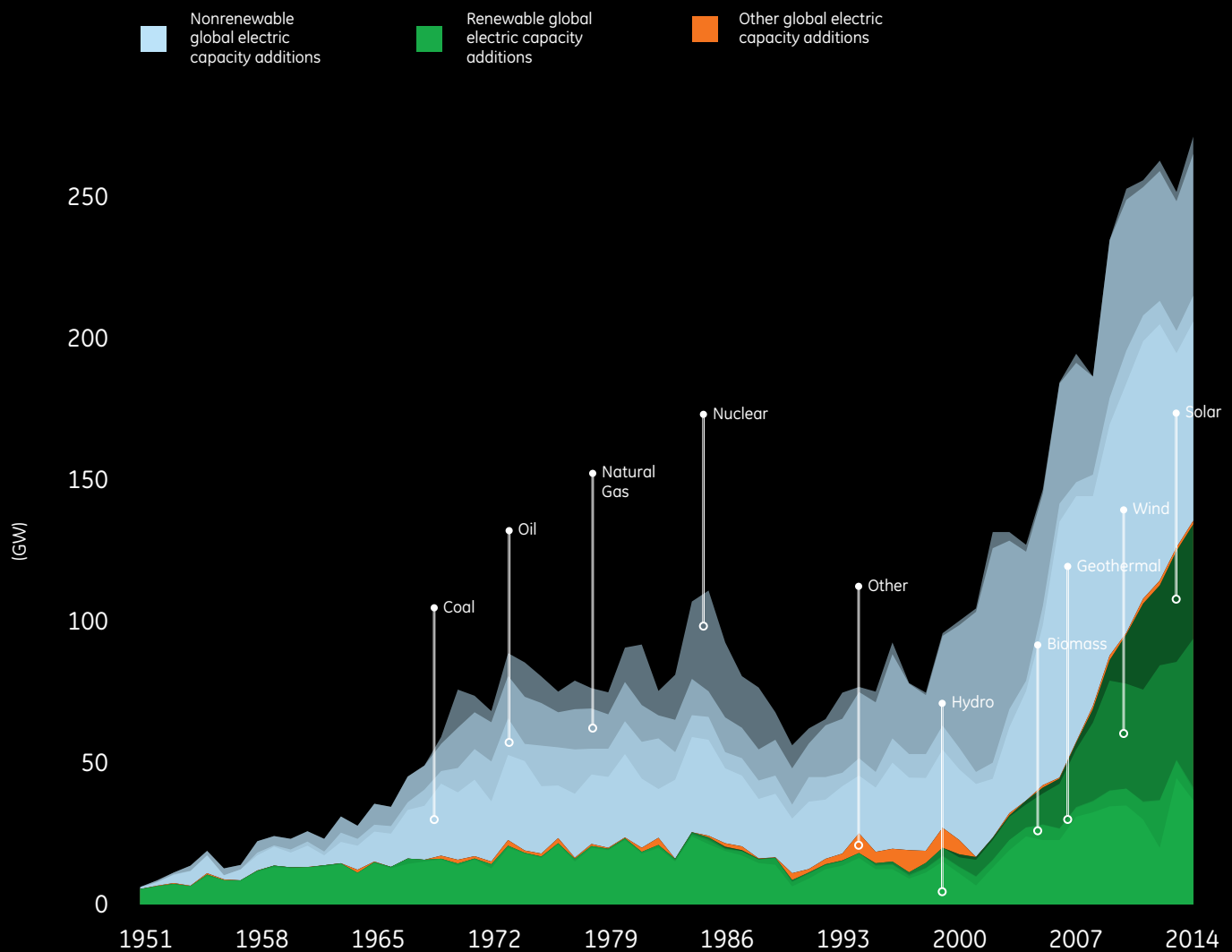
## From Transition to Transformation

Three important trends are supporting and enhancing the renewable energy era today:

- First, the acceleration of renewable energy is occurring in both a centralized and a distributed manner. Wind, hydro, biomass, concentrating solar power (CSP), and geothermal power are being added primarily as centralized resources—just like conventional generation sources—while solar PV is being added in both utility-scale and distributed rooftop applications. This combination of centralized and distributed generation mirrors the current evolution of the global electric power system, which itself is moving away from a balkanized hub-and-spoke model toward hybrid networks with both centralized and distributed elements.
- Second, renewables are increasingly being added as part of integrated systems that can contain conventional and renewable energy technologies. Hybrid natural gas and solar PV systems are one example of this emerging trend. The integration of energy storage both within the transmission and distribution (T&D) system and onboard electricity generators is another example.
- Third, the renewable energy transition is occurring against the backdrop of the blending of physical and digital assets. Examples include the emerging smart grid that adds intelligence to the T&D system, and Internet-enabled digital systems onboard generation technologies such as GE's Digital Wind Farm. The integration of digital technologies with physical renewable energy assets promises to further enhance the value proposition of renewables.

# Figure 4. Global electric capacity additions by source (1950–2014)

Over the last 10 years, centralized and distributed renewable energy power plant construction has surged. At the same time, in order to meet growing electricity demand, the world has experienced a surge in the development of all types of power plants.



**Source:** GE, International Energy Agency (IEA), International Renewable Energy Agency (IRENA).





These aspects of the renewable energy transition are fueling a broader transformation of electricity production, distribution, and consumption. This is occurring concurrently with the renewable energy transition. The ultimate result will be an increasingly diverse global electric power system that is more efficient, resilient, and intelligent, and will have a lower environmental impact over time.

To be clear, the start of renewable energy transition doesn't mean that fossil fuel and nuclear sources are going away. In fact, these sources will continue to play an important role in the global electric power system. Nonrenewable electric power sources account for 77 percent of global electric capacity today and will remain critically important to meet growing electricity demand across the globe. Furthermore, some nonrenewable technologies, such as natural gas turbines, will be needed to facilitate greater levels of variable renewable energy adoption because their flexibility will be required to complement renewables.

The renewable energy transition is the start of a decades-long process. The duration of energy transitions is explained by physicist Steven Koonin: former Under Secretary for Science for the US Department of Energy. According to Koonin, "The energy system evolves much more slowly than other technology-dependent sectors" because of its "sheer scale ... and its ubiquity throughout our society." Other factors include the amount of capital that is invested, the fact that infrastructure like power plants lasts so long, and the interconnectedness and interdependence of the whole system.<sup>10</sup>

GE's new business, Current, is a digital power service built to transform the way the world uses energy. Current brings innovation in one place by combining GE's capabilities in LED, solar, energy storage, distributed generation, and electric vehicle

infrastructure into a sustainable energy ecosystem powered by GE's Industrial Internet platform Predix. The Current technology ecosystem will benefit customers by saving them an estimated 10 to 20 percent on their energy bills and it will help utilities better manage the load on the energy network. Current is presently working with businesses such as Walgreens, Simon Property Group, Hilton Worldwide, and Intel to solve energy needs and increase control and independence, all while saving costs.

### Environmental Benefits

The environmental benefits of accelerated renewable energy deployment are clear and unambiguous. Renewable energy provides domestic energy security for countries that prefer to rely upon indigenous energy supplies in order to meet critical power needs. In addition, renewable power technologies contribute to sustainability by reducing the direct environmental emissions associated with power production and delivery. Electricity generation from fossil fuels led to approximately 14,000 million metric tons (Mt) of CO<sub>2</sub> emissions in 2014.<sup>11</sup> Increasing amounts of renewable power generation will reduce this level. GE estimates that electric sector CO<sub>2</sub> emissions have already been reduced by up to 8 percent as a result of non-hydro renewable power generation alone. Accelerated levels of renewable electric generation over the next decade will reduce CO<sub>2</sub> emissions even further.

Increases in renewable energy also reduce the water footprint of electricity generation. This is increasingly important at a time when local and global water scarcity has become an economic and environmental challenge. Seven hundred and fifty million people around the world lack access to safe drinking water today, and within the next decade, one-third of the world's population will live in water-stressed regions. Water is also a

basic input to the global economic system and is essential for agricultural and industrial production. Global industrial water demand alone is expected to increase by 250 percent by 2030.<sup>12</sup> Increasing levels of renewable energy will lead to a substantial reduction in water consumption and withdrawal in the power sector. For example, a recent analysis indicates that water withdrawals in 2030 could decline by nearly 50 percent for the United Kingdom; by more than 25 percent for the United States, Germany, and Australia; and by over 10 percent in India.<sup>13</sup>

### The Path Forward

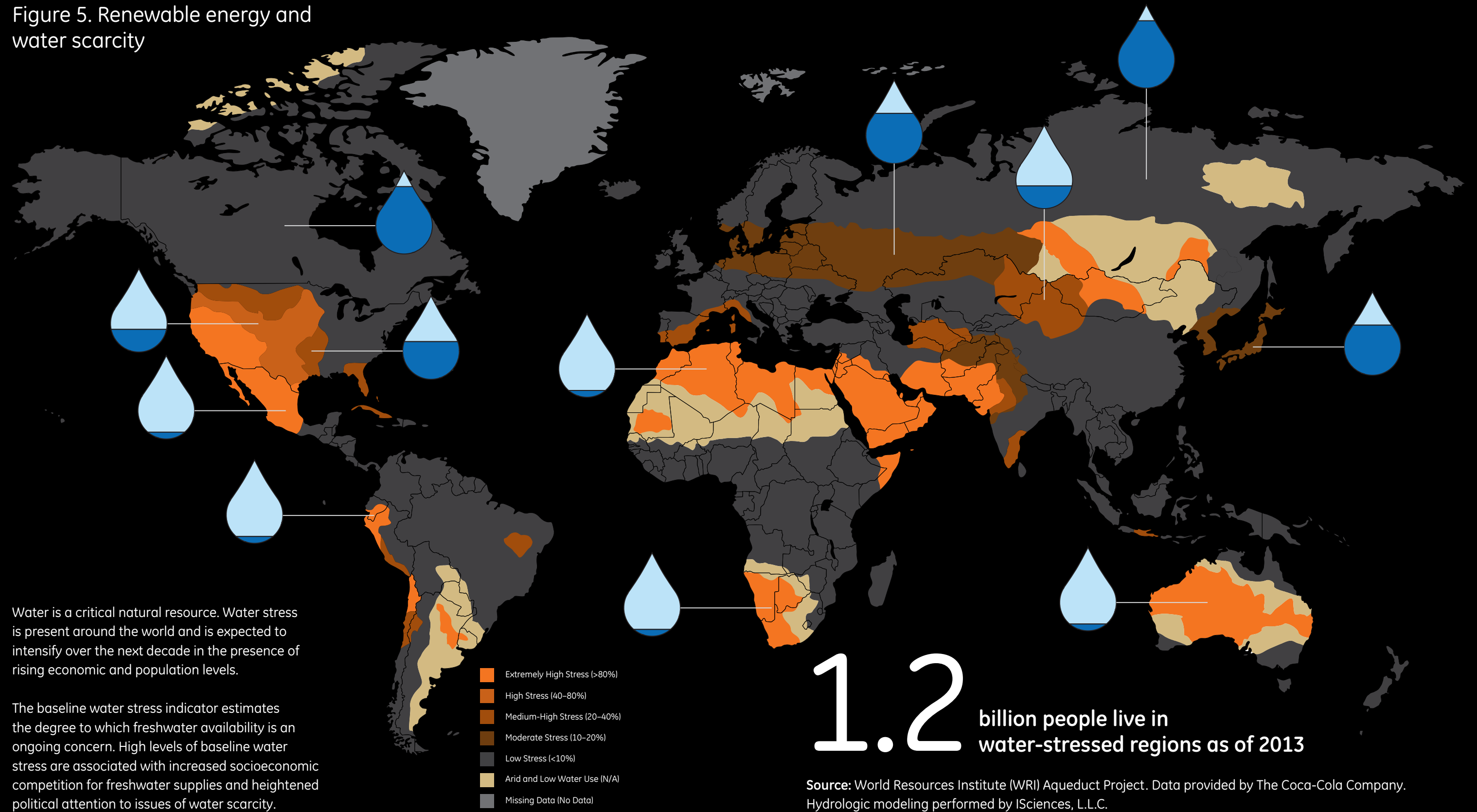
However, the path forward contains both challenges and opportunities:

- Stakeholders must work together to coordinate and integrate electricity planning, develop rules for market evolution that enable system flexibility, expand access to diverse resources, and improve system operations.<sup>14</sup>
- In order to accommodate the increasing levels of variable renewable energy, both demand- and supply-side technologies within the electric system must become increasingly flexible.
- Greater levels of deployment and utilization of the existing grid-friendly capabilities of renewables will be required, and new capabilities must be developed.
- Technology innovations like more sophisticated methods of forecasting the wind and sun, and cost-competitive energy storage solutions will be needed to allow renewables to become more predictable and to better manage variability.

- The Industrial Internet must be fully leveraged to enable greater control and coordination across the grid.

In GE's view, innovation is the key to transforming these challenges into opportunities in the years ahead.

Figure 5. Renewable energy and water scarcity







## II. RENEWABLE ENERGY INNOVATION

Renewable energy is not a new source of power. The world's first hydropower plant began operating in Wisconsin in 1882. The first geothermal power plant was built in Italy in 1911. Early prototype wind turbines were up and running in the United States and Denmark by the 1890s, and Bell Labs developed the first practical silicon solar cell in 1954. However, what is new today is the rapid technology innovation that has occurred in the last decade, particularly for wind energy and solar PV technologies. And this is just the beginning. Looking ahead, new innovations are on the horizon that promise to make these technologies even more productive and cost-effective.

### Wind Power

GE's history with wind power technology started in 1941 when the company provided technical support and the electric generator for the world's first megawatt-scale wind turbine in Vermont.<sup>15</sup> Later, GE continued its wind power efforts with the construction of the world's first 2 megawatt (MW) turbine in 1978.<sup>16</sup>

GE's modern wind power journey began in 2002 with the acquisition of certain assets of Enron Wind Corp.<sup>17</sup> At that time, global wind power capacity stood at 31 GW, less than one-tenth of the 2014 level. Wind power had been under development for decades but was just beginning to become part of the global electric power system. Europe was the world leader in wind power capacity after providing both investment and policy support for the infant wind industry throughout the 1980s and

### GE's Role

GE is one of the world's leaders in wind turbine manufacturing and services. Now, with the addition of the Alstom wind power portfolio, GE has added an even broader portfolio of onshore and offshore wind turbines and services.



|                                   |                                   |                                                |
|-----------------------------------|-----------------------------------|------------------------------------------------|
| 51 <sub>GW</sub>                  | 370 <sub>GW</sub>                 | 2.8%                                           |
| 2014 Global<br>Capacity Additions | 2014 Global<br>Installed Capacity | 2014 Share of Global<br>Electricity Generation |

### Recent Innovations

1. Upsizing rotors and improved reliability with advanced materials and control systems and manufacturing economies of scale
2. Advances to make wind power more grid-friendly

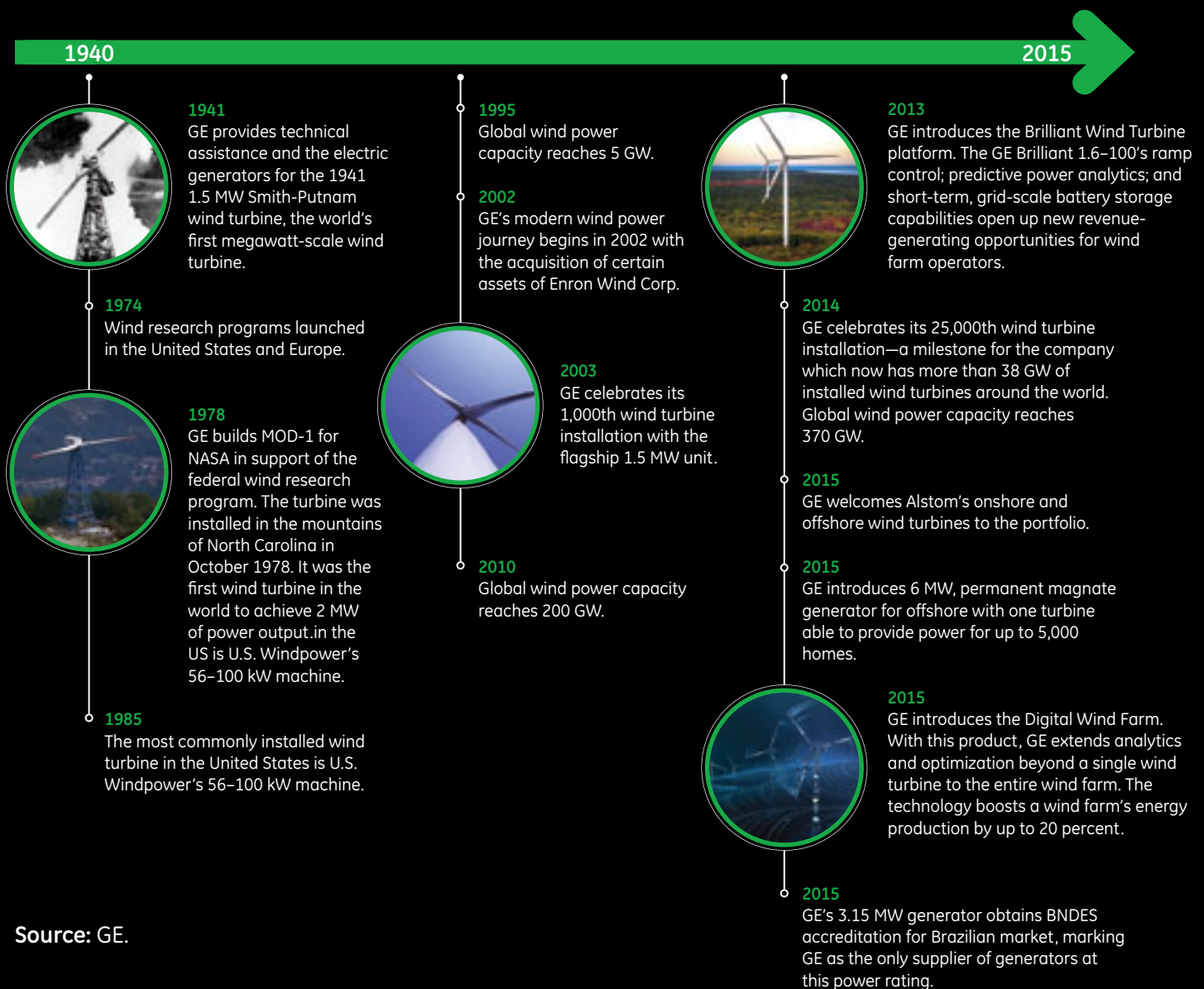
### Future Innovations

1. Continued innovations in the digitization of wind power
2. New approaches to the customization of wind turbines for site-specific conditions and the modularization of components for easier transport and erection

1990s, and accounted for 75 percent of global wind capacity. By 2002, wind power technology had made significant progress and was on its way toward the mainstream, leaving behind its days as an alternative energy technology.

## Figure 6. GE's wind power journey

GE's modern wind power journey started in 2002. In 2013, GE introduced the Brilliant Wind Turbine platform that achieved better efficiency and higher output through integrated energy storage. In 2015, GE launched the Digital Wind Farm, a product portfolio comprised of GE's newest wind turbines, predictive analytics, and performance optimization controls.



Source: GE.



However, more progress was necessary to bring costs down and increase reliability to a level that enabled wind power to begin to compete economically with conventional generation sources and plug into the centralized utility network. Wind turbines were challenged by reliability problems that inhibited their use in the utility-scale global power system.

GE got to work solving these challenges through scale and innovation. GE implemented key design changes, instituted new manufacturing processes, and accelerated testing for gearboxes and blades. Gearbox improvements as well as the introduction of direct drive gearless wind turbines helped bring down failure rates to less than 10 percent over a 20-year period. These steps helped accelerate wind power's market expansion in global utility-scale markets.

GE's next innovation was to apply its ability to scale technology at the industrial level to our wind power operations. In 2004, GE was shipping wind turbines at a rate of 10 turbines per week. Today, the company ships more than 10 turbines per day. By applying industrial scale to wind turbine manufacturing, GE was able to reduce costs and improve reliability and performance through continuous learning.

While scaling wind turbine manufacturing operations, GE, along with the rest of the wind industry, also focused on developing larger wind turbines to ensure performance improvements and start driving the LCOE down. Through these efforts, the wind industry was able to achieve a doubling of wind turbine size approximately every five years in the 1990s and early 2000s so that by 2005, the average wind turbine size was 1.5 MW, up from 300 kilowatts (kW) a decade earlier and 75 kW in the 1980s. At the same time, as power capacity was increasing, so were the length of the blades

and the height of the tower. The average 1.5 MW wind turbine of 2005 had a 70-meter (m) rotor diameter and a 60 to 80 m hub height, a big jump in dimensions when compared to the 17 m rotor diameters and 20 m hub heights of the 1980s. While the trend toward larger MW ratings continues in all regions, turbines have grown more in rotor diameter and height than in nameplate capacity, especially in onshore applications.

Because it has the largest impact on LCOE and energy capture, GE and other wind turbine manufacturers continue to work on innovations in design, materials, process, and logistics to extend rotor diameter. The 40 to 45 m blade is the current mainstream segment, but by 2020, 50+ m blades are expected to become the global mainstream. For example, the blades of Alstom Haliade 6 MW wind turbine destined for the offshore environment span 73.5 metres, sweeping over an area that can almost span four Airbus A380s. The increase in rotor size has led to rapid growth in the swept area of the rotor. Swept area increases are outpacing increases in nameplate capacity. This has led to an increase in energy capture per watt of rated capacity. As a result, over the last decade, wind turbines have seen more energy for their rated capacity, with capacity factors increasing considerably.<sup>18</sup> At the same time, by delivering higher production, larger rotors deployed in sites with higher wind conditions have been crucial for boosting project economics of some of these ventures that might not have been viable in other circumstances. In the quest to increase production while improving competitiveness, GE has developed its tensioned fabric blade, which has been recognized by the industry as having high potential for weight and cost reductions. With the acquisition of Blade Dynamics, GE will accelerate and intensify its efforts in blade technology innovation.

Increasing tower heights and stronger winds at higher altitudes have also contributed to the increasing capacity factors of wind turbines and to reducing capital costs, with towers of 120+ m not uncommon today. Wind turbine manufacturers are working on overcoming the challenges associated with these large structures, including structural integrity, logistics, and permitting issues. GE's Space Frame Tower, for example, can be easily delivered to and assembled at any project site, including those where terrain makes movement of traditional tower sections difficult.

While rotor blade and tower innovations over the last decade have resulted in significant improvements in terms of output and lower cost of energy for wind power, other innovations in wind turbine design have allowed wind power to become increasingly compatible with the T&D systems and have lowered the costs of integrating variable wind technologies with the T&D network. Today, in the United States, most independent system operators (ISOs) dispatch wind, and all must comply with Federal Energy Regulatory Commission (FERC) Order No. 661—a low voltage and low frequency ride-through requirement. However, to become even more grid-friendly, wind turbines need to provide synthetic inertia, primary frequency response, and secondary frequency response. Over the last decade, GE has pioneered innovations in each of these areas. Today's wind turbines now offer features designed to improve the ability of wind turbines to act like a dispatchable power plant. Improved wind forecasting techniques have also increased the reliability of wind power commitments and reduced curtailments.

GE has invested over \$2 billion over the last decade in wind power R&D and used the GE Store to accelerate wind turbine innovation. The GE Store is GE's term for the synergistic benefits created by GE's ability to share insights, innovation, culture, and processes across its broad range of global industrial

businesses. The GE Store is a place where every GE business can come for technologies, product development, and services that no one else can provide.

In the case of wind power, the GE Store has enabled GE to accelerate wind turbine innovation over the last decade. GE leveraged GE Global Research—an army of more than 3,000 scientists, engineers, and researchers working together to deliver technical breakthroughs to GE customers—to apply technologies and insights from other fields to make its wind turbines better. GE uses imaging algorithms designed for the healthcare system in sensors embedded in our wind turbine blades, gearbox innovations from GE Transportation, control systems from GE Aviation, and computational fluid dynamics models from gas turbines within GE Power.

The result has been increasingly competitive and reliable wind power over time. After a decade of investment and innovation, in 2012, GE launched a new 1.6–100 wind turbine, which was the most efficient 1.5 MW wind turbine in the world. With the introduction of the 1.6–100, GE improved the capacity factor from 35 percent 10 years ago to over 50 percent today in the best wind regimes.

*GE has invested over \$2 billion over the last decade in wind power innovation. GE has also leveraged the GE Store, which accelerated wind turbine innovations over the last decade by bringing innovations from other industries to wind power. The result has been increasingly competitive and reliable wind power over time.*



## Brilliant Wind Turbine™

With the introduction in 2013 of the 2.5 MW Brilliant Wind Turbine, GE demonstrated additional ways to reduce the cost, improve the reliability, and increase the performance of wind turbines beyond upsizing the rotor. When launched, the 2.5–120 was the world's most efficient, high-output wind turbine, offering a 2 percent increase in capacity factor and a 15 percent increase in annual energy production (AEP). One of the noteworthy features of the Brilliant Wind Turbine is the integration of batteries for energy storage. The battery technology enables short-term energy storage as part of the complete turbine system. Integrating the battery into the wind turbine allows wind farm operators to benefit from energy storage without the costs of a farm-level battery storage installation.

## Digital Wind Power

Integrating energy storage into wind turbines was a significant step forward in wind power innovation in 2013. In 2015, GE made another leap with the introduction of the Digital Wind Farm. With this solution, GE extends analytics and optimization beyond a single wind turbine to the entire wind farm. GE harnessed the power of the emerging Industrial Internet to create the Digital Wind Farm, a dynamic, connected, and adaptable wind energy ecosystem that pairs world-class turbines with digital infrastructure for the wind industry.

The Digital Wind Farm technology boosts a wind farm's energy production by up to 20 percent and could help generate up to an estimated \$50 billion value for the wind industry. The Digital Wind Farm uses interconnected digital technology—often referred to as the Industrial Internet—to address a long-standing need for greater flexibility in renewable power. The technology will help integrate

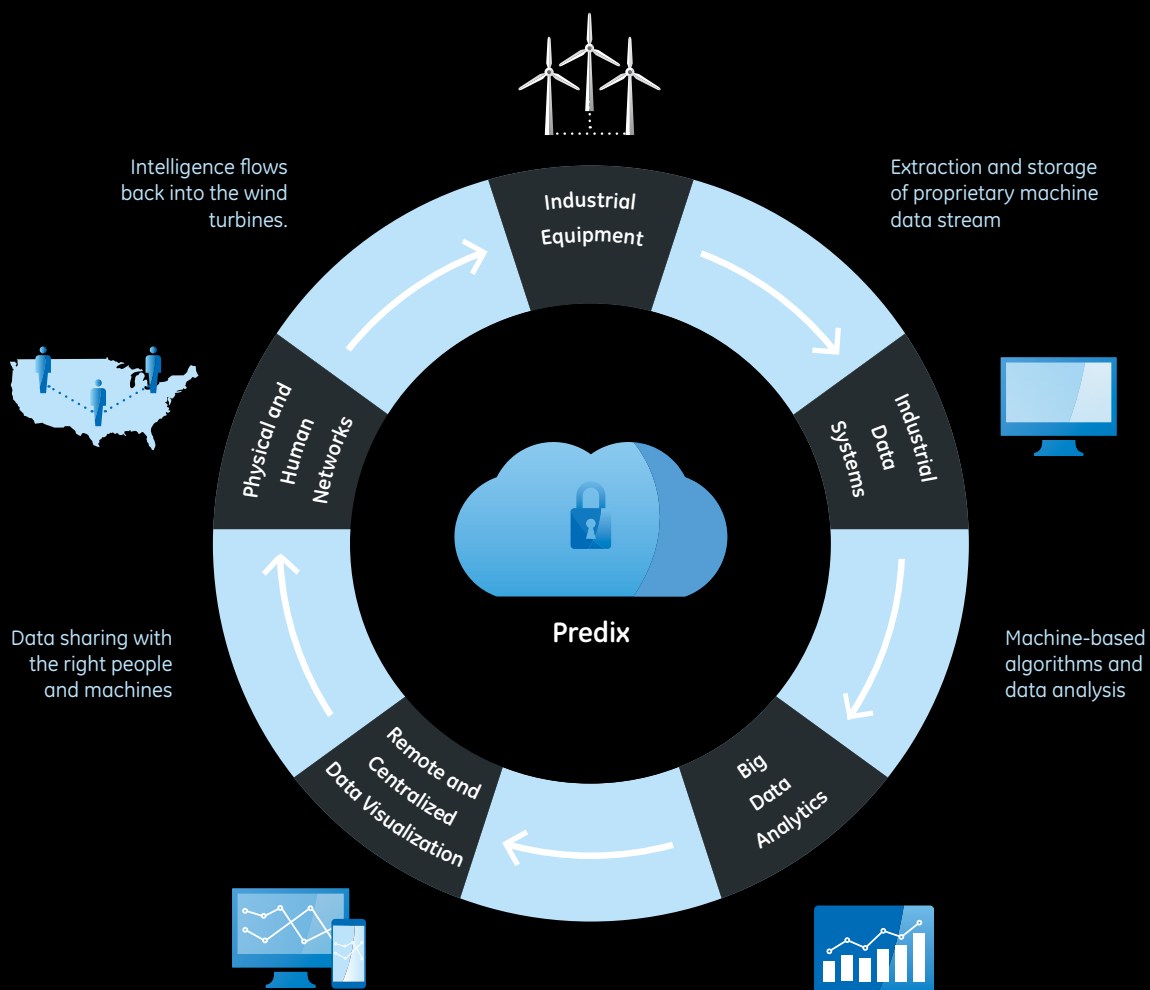
renewable power into the existing power grid more effectively.

GE's Digital Wind Farm is a product portfolio comprised of GE's newest wind turbines, predictive analytics, and performance optimization controls that over the course of a wind farm's life will improve its energy output compared to previous technology with a standard configuration. By using GE's 2.0–2.4 MW wind turbine, combined with multiple rotor lengths and tower height options, a wind farm can be optimized to address effects such as shear, wakes, and turbulence intensity. The 2.0–2.4 MW turbine model leverages a universal machine head, hub, and down tower assembly to simplify physical optimization of the wind farm layout and reduce installation time and cost. By simulating site characteristics to select a unique turbine configuration for every pad, the annual energy production of a wind farm will increase when compared to one built with a single turbine type.

The second portion of the Digital Wind Farm is the optimization of turbine performance and equipment life through the use of predictive analytics software. GE's Predix, an open developer software platform, provides the digital infrastructure beneath the 2.0–2.4 turbine hardware of the Digital Wind Farm, allowing a customer to connect, monitor, predict, and optimize both unit and site performance. Through constant collection of real-time data, weather, component messages, service reports, and performance of similar models in GE fleets, a predictive model is built. This model serves as the basis for forecasting all maintenance needs and creating a plan of the day for wind farm operation. This digital feedback loop allows the farm operator to eliminate unplanned maintenance events, reduce operating expenses, and capture higher power output from machines that are operating more efficiently and reliably.

## Figure 7. Renewable energy and the Industrial Internet

The Digital Wind Farm optimizes turbine performance through the use of predictive analytics software. GE's Predix, an open developer software platform, provides the digital infrastructure beneath the Digital Wind Farm, allowing a customer to connect, monitor, predict, and optimize both unit and site performance.



Source: GE.





The Digital Wind Farm also employs GE's Wind PowerUp™ Services. PowerUp harnesses the Industrial Internet to drive higher power output and create new revenue streams for wind farm operators. PowerUp analyzes tens of thousands of data points in a wind farm every second in order to fine-tune performance and increase output by up to 5 percent and increase profits by up to 20 percent. PowerUp is already at work in the field, improving wind turbine performance. For example, since European utility E.ON's 469 strong wind turbine fleet in the United States enrolled in PowerUp, power output has increased by 4.1 percent, the equivalent of adding 19 additional GE wind turbines. Within the context of the Digital Wind Farm, PowerUp instructs individual turbines to boost performance in response to changes in wake, shear, and turbulence. This enables each turbine to produce more energy over the project lifecycle without compromising turbine design life.

### Wind Power Today

Wind power has come a long way over the last decade. In 2014, a record 51 GW of wind capacity was added across the globe. Wind power investments reached \$100 billion, and total installed wind power capacity hit 370 GW. Average growth in wind power capacity since 2005 was 23 percent. The wind industry is much more globally diversified today than it was a decade ago, when 75 percent of the installed capacity was in Europe. Today, 31 percent of the installed capacity is in China, 25 percent is in Europe, and 18 percent is in the United States.<sup>19</sup>

GE's wind turbine offerings have evolved accordingly to meet the needs of the growing global marketplace. Our current onshore wind turbine portfolio includes wind turbines with hub heights ranging from 65 to 139 m, and rated capacities from 1.7 to 3.2 MW. GE offers a broad set of wind

turbines that operate in all wind speed environments and size ranges.

With the addition of Alstom's wind power solutions, the GE family of wind turbines has become even broader. Alstom offers onshore and offshore wind turbines ranging from 1.67 to 6 MW, providing solutions for all types of geographical locations and weather conditions. Additionally, climate kits allow operation in deserts or very cold environments. With a design optimized for simple assembly, erection in complex terrains is even easier. Alstom turbines also come with a unique comprehensive monitoring and control system. Other design details contribute to low noise, safe operations, and convenient maintenance.

The last decade has been one of tremendous innovation for wind power—from sub-megawatt wind turbines with reliability challenges in 2002 to the Digital Wind Farm in 2015. The journey has moved wind power into the mainstream through industrial scaling, technical innovation, and economic improvements. Looking ahead, the next generation of wind power innovations is even more promising.

### Next Generation Wind Power

As impressive as the last decade of wind power innovation has been, the future holds even greater promise. Wind power innovations just entering the market today and those in our research centers offer a glimpse of the future of wind power. GE is developing new technologies in its research laboratories and is testing the latest innovations in the field.

Individual wind turbine and farm-level analysis and optimization will continue to expand and set the new standard for wind power projects. These innovations will enable wind farm operators to produce more energy and generate greater revenue than

was previously possible without the integration of large-scale battery storage and the addition of data and analytics through the Industrial Internet. The Digital Wind Farm is not a trendy innovation of today; it is the path forward for tomorrow. As with all aspects of the industrial economy, the blending of the physical and digital will become commonplace in tomorrow's wind farms.

*The digitization of wind power is the path forward. As with all aspects of the industrial economy, the blending of the physical and digital will become commonplace in tomorrow's wind farms. The net result will be increased performance and greater revenue at a lower cost.*

The next generation of this physical-digital integration is the development of even smarter control systems. LIDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. LIDAR can be installed on the top of wind turbines to get horizontal projections for winds heading toward a wind turbine. As such, turbines can adapt to the winds heading toward them before the winds arrive. GE is a strong believer in LIDAR systems, which are currently under development and are being actively deployed on wind turbines by GE and other manufacturers.

Pentalum Technologies, which develops cost-effective LIDAR systems for wind turbines, received a strategic investment from GE Ventures in 2013. In addition to LIDAR, wind turbines themselves can also be used as sensors to predict and proactively respond to changing wind conditions. In

the near future, forward-deployed sensing wind turbines can “talk” to the other turbines in the wind farms and help them respond proactively to changing conditions.

These solutions are enabled by the physical-digital integration of the wind turbine. Additionally, there are some exciting hardware-only advances on the horizon. The key for wind power innovation over the next decade is to achieve greater productivity without increasing the size and weight of the tower and rotor. Blades and towers can be difficult to transport to remote locations with the best wind resources. These components or their parts need to be made lighter and smaller so that they are easier to transport.

GE's Ecomagination-funded experimental Energy Capture Optimization by Revolutionary Onboard Turbine Reshape (ecoROTR) is one solution. EcoROTR is a small dome placed at the center of a wind turbine that deflects the wind toward the blades, enabling greater energy capture. EcoROTR also reduces the size of wind turbine blades because shorter blades are needed once the ecoROTR is in place at the center of the hub. EcoROTR is one of the technologies that has been developed as a result of GE's 10-year commitment to Ecomagination. GE began testing ecoROTR at the GE wind test center in Tehachapi in the spring of 2015, and our scientists believe that it may be able to provide future wind turbines with a 3 percent performance boost. These numbers add up when multiplied across entire wind farms with dozens of wind turbines.

GE's new space frame tower is another solution. The five-legged lattice tower uses architectural fabric to reduce the amount of steel required, which helps to cut manufacturing costs. Space frame towers are modular, which enables easier transport on standard trucks. Space frame towers can also reach higher heights and better wind







speeds, which improves turbine performance and reduces costs. In March 2014, GE installed a prototype 97 m space frame tower in Tehachapi. The five-legged closed lattice tower had about 4,500 structural bolts, compared with 450 in a conventional tubular tower. The GE space frame tower enables towers to be larger and taller but with smaller, lighter components. This is the future of wind power.

*Innovation is an uncertain process, and new, unexpected technologies will likely emerge. The possibilities are endless, and innovations in new areas, such as advanced manufacturing, have the potential to change the nature of wind turbine manufacturing. As impressive as it was, the last decade may simply have been a prelude to the coming revolution in wind power.*

Innovation is an uncertain process, and new, unexpected technologies will likely emerge. The possibilities are endless, and innovations in new areas, such as advanced manufacturing, have the potential to change the nature of wind turbine manufacturing. Wind turbine blades of the future may be printed on-site, thereby avoiding the need for transportation altogether. Advanced manufacturing technologies may enable wind turbines to be fully customized to meet the needs of particular wind sites.

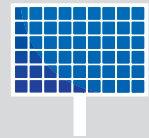
Whether this is the future direction of wind turbines or not, GE is hard at work developing the

next generation of solutions for this critical global industry. Given the web of potential future innovations, it's easy to be optimistic about the potential for additional cost and performance improvements for wind power. As impressive as it was, the last decade may simply have been a prelude to the coming revolution in wind power.

## Solar Power

### GE's Role

Current is focused on providing integrated distributed energy solutions, which include solar and energy storage. GE also provides utility-scale solar inverters and control systems through GE Energy Management and invests in renewable energy through GE Energy Financial Services and GE Ventures.



|                                   |                                   |                                                |
|-----------------------------------|-----------------------------------|------------------------------------------------|
| 40 <sub>GW</sub>                  | 181 <sub>GW</sub>                 | 0.1%                                           |
| 2014 Global<br>Capacity Additions | 2014 Global<br>Installed Capacity | 2014 Share of Global<br>Electricity Generation |

### Recent Innovations

1. Rapid cost reductions due to global manufacturing capacity expansion and technology innovations such as increasing efficiencies
2. Business and financial model innovations such as the solar PPA and yieldcos have lowered solar costs and made solar more accessible
3. Setting the industry standard with LV5 1.5 kV inverter technology, lowering the cost of electricity from a typical solar power plant by 3%

### Future Innovations

1. Continued cost reduction and efficiency improvements
2. Continued development of integrated, distributed systems with energy storage, energy efficiency, and analytics



Current is focused on providing integrated distributed energy solutions, which include solar and energy storage. GE also provides utility-scale solar inverters and control systems through GE Energy Management and invests in renewable energy through GE Energy Financial Services and GE Ventures. GE also has a commercial partnership with panel manufacturer First Solar.

Current is focused on providing integrated distributed energy solutions, which include solar and energy storage. GE also provides utility-scale solar inverters and control systems through GE Energy Management and invests in renewable energy through GE Energy Financial Services and GE Ventures. GE also has a commercial partnership with panel manufacturer First Solar.

GE's solar PV efforts are enabled by the large solar power cost reductions over the last decade. In fact, as noted, of all renewable power technologies, solar PV technologies have experienced the most dramatic improvements in cost over the last decade. As a result of these cost reductions and strong solar support policies, the global solar PV market experienced a record year of growth in 2014 and reached a cumulative capacity of 181 GW. This means that the solar PV installed capacity has multiplied by a factor of 100 in 14 years of development.<sup>20</sup>

Solar PV cost reductions have been the result of a combination of innovation and the rapid expansion of global solar PV manufacturing capacity. During the 1980s and 1990s, solar PV cost reductions were driven by increasing plant size. As the annual production capacity of manufacturers grew from hundreds of kilowatts to hundreds of megawatts, economies of scale were realized in raw materials and equipment purchasing. Companies also adopted leaner process control techniques found in more mature sectors such as semiconductors.

Global PV manufacturing capacity ramped up at an accelerated rate over the last decade. This led to a tenfold increase in PV production between 2007 and 2013, when production rose from 4 to 40 GW.<sup>21</sup> After a decade of continuous expansion, China's share of global PV manufacturing capacity reached two-thirds by 2012. The glut of capacity, combined with strong support policies in Europe, led to record solar PV installations at falling costs. Crystalline silicone PV cost reductions were also driven by significant reductions in polysilicon prices, which peaked in 2008 at almost \$500/kg due to supply shortages but have since fallen dramatically and are now trading at less than \$20/kg.

Although much of the solar cost reductions were driven by increases in solar manufacturing capacity and raw materials price declines, solar PV technologies have also experienced significant technology improvements over the last decade. The average efficiency of commercial silicon modules has improved in the last 10 years by about 0.3 percent per year, reaching 16 percent in 2013. Record cell efficiencies for crystalline silicon PV improved to 25 percent in 2014.<sup>22</sup>

In addition to cost reductions coming from PV technology improvements, constant advances in inverter technology and most notably the new industry 1.5 kV standard set by GE's LV5 have lowered the cost of building and operating a plant by up to 30 percent. As the next generations of inverters adopt silicon carbide, the scale of savings promises to continue to increase.

After decades of technology development, thin film solar technologies made significant progress in the last decade. When First Solar began production on its first commercially available cadmium telluride (CdTe) thin film, it had an efficiency of 7 percent. In 2015, the company announced that



it had achieved a world-record efficiency of 18.6 percent for an advanced full-sized module.

### Solar as a Service

One of the greatest solar power innovations over the last decade was not a technical success, but rather the development of a financial model that unlocked large customer segments and accelerated solar growth in the United States by making it easier for residential, commercial, and industrial consumers to purchase solar power. The solar power purchase agreement (PPA) model was pioneered by SunEdison, Renewable Ventures, and Sunrun in 2006 and 2007 as a way to enable solar power developers to use the same approach that independent power producers (IPPs) use when selling electricity from large, centralized power plants to utility customers. The solar PPA model is now used extensively in the US solar industry by solar power developers.

The solar PPA is one approach to the third-party ownership (TPO) model. Using the solar PPA approach, an independent third-party solar developer builds, owns, and operates a solar PV system on a residential, commercial, or industrial site. The developer then sells the electricity to the customer at an agreed upon rate via a long-term contract. This allows the customer to have the benefits of solar power at a fixed price per kilowatt hour without having to pay the large upfront costs associated with purchasing and installing the solar equipment. This also allows the developer to fully leverage available national and local incentives for solar power, which often require both equipment ownership and a suitable tax appetite (which many host customers do not have).

The PPA approach is an attractive option for solar PV. However, in some jurisdictions where third-party PV owners are constrained or prohibited,

solar lease structures have gained traction as an alternative TPO option. Under a solar lease arrangement, a homeowner or business enters into a service contract to pay scheduled, pre-determined payments to the solar developer, which installs and owns the solar system on the customer's property.

The success of the PPA approach and other TPO models applied to solar PV serve as an example for other distributed technologies. TPO models hold promise for the acceleration of emerging technologies such as fuel cells, hybrid distributed systems, and energy storage. TPO may be the key to advancing the deployment of a broad range of distributed power systems.

### Next Generation Solar

Looking ahead, solar PV technologies have the potential to experience continued cost reductions. These cost reductions are likely to be driven both by technical and financial innovations. The next financial innovation for the solar industry is already gaining traction. The solar industry is now adopting a financing vehicle known as a yieldco, which has the potential to attract billions of dollars of investment and further lower financing costs for solar power systems.

In 2012, the yieldco concept was initiated by adopting the 50-year-old real estate investment-trust program to renewable energy by forming an IPP to own and operate renewable energy projects. A yieldco is a publicly traded company that yields predictable cash flow and distributed income to the shareholders. The first renewable energy yieldco was Brookfield Renewable Energy Partners, which was listed on the New York Stock Exchange (NYSE) in 2012. The success of Brookfield opened up the door to other renewable energy yieldcos. In 2014, SunEdison created TerraForm Power, and in June

## Figure 8. Solar power purchase agreement (PPA) model

The solar power purchase agreement (PPA) model is a financial innovation that has spurred the growth of solar PV in the United States. New financial innovations like yieldcos and green bonds will help support continued renewable energy growth moving forward.



**Source:** Adapted from Katherine Kollins, Bethany Speer, and Karlynn Cory, "Solar PV Project Financing: Regulatory and Legislative Challenges for Third-Party PPA System Owners" (National Renewable Energy Laboratory: Golden, Colorado, 2005).



2015, First Solar and SunPower created 8point3 Energy Partners, which is now trading on the NYSE. Yieldco initial public offerings have raised capital from public equity markets and lowered financing costs for solar power developers. According to Deutsche Bank, yieldcos reduce the cost of equity from 10 percent to less than 5 percent.<sup>23</sup>

The yieldco concept is spreading globally, first to Asia. Neo Solar Power Corporation of Taiwan has announced that it is planning on establishing a yieldco in 2015. The emergence of yieldcos in developing markets such as India and China has the potential to lower solar financing costs and lead to solar power cost reductions of up to \$40/MW.<sup>24</sup>

On the technology and manufacturing side, there are several areas that provide an avenue for solar power cost reductions. Cost reductions on a per-watt basis will occur as solar PV efficiencies continue to increase and as total installed system prices decline. Historically, consistent improvements in PV cell efficiency have been realized for every PV technology, and module efficiency has followed this trend. This historical pattern is expected to continue over the next decade.

Total installed system price reductions can occur as a result of reductions in the production cost of PV modules, power electronics, and balance of system costs. The production cost of modules will decline as material use is reduced. The cost of crystalline silicon will continue to fall as losses are minimized and wafers are made even thinner. Improved manufacturing processes and mass production efficiencies will continue to push down module costs.

Power electronics include inverters (which convert DC electricity produced by the PV module into AC electricity used by the transmission systems) and transformers (which step the electricity up to the

appropriate voltage). These are often combined into a single integrated device and referred to as the inverter, like GE's LV5 inverter and GE's Brilliance Solar Inverter and its SunIQ platform for solar farms. When compared to the majority of installed inverters on the local market, GE's Brilliance Solar Inverter, with its innovative two-stage configuration, results in higher conversion efficiency and operating range, and superior grid performance. The larger capacity satisfies the need of large-scale solar farms by reducing the number of inverters and maintenance work required, ultimately bringing increased reliability.

### Concentrating Solar Power

Concentrating solar power (CSP) technologies produce heat through the use of mirrors and then use the heat to produce electricity. CSP technologies are most useful in large, centralized power applications and are currently less economically competitive than solar PV technologies in stand-alone applications. One of the largest advantages of CSP compared to solar PV is that CSP can be equipped with thermal storage to make CSP plants flexible and dispatchable. Thermal storage is less costly than battery storage and entails fewer losses. This makes CSP a strong grid complement to variable renewable energy technologies such as wind and solar PV. CSP technologies are less commercially established than solar PV, but global CSP capacity continues to gradually increase, growing 27 percent to 4.4 GW in 2014. New innovations will continue to advance CSP technology, driving down costs and increasing performance over the next decade.

Although solar parabolic troughs are the dominant CSP technology today, one of the most promising CSP technologies is the solar power tower, which consists of a field of mirrors that reflects sunlight to a large tower in the center of the field. Alstom offers everything from complete turnkey CSP plants to individual CSP components. In September 2011,

Alstom signed a contract with Cobra Thermosolar Plants Inc. to supply a 125 MW steam turbine and generator to the Crescent Dunes power tower project near Tonopah in Nevada. The project includes 17,500 heliostat mirrors that collect and focus the sun's thermal energy to heat molten salt flowing through an approximately 160 m tall solar power tower. The molten salt circulates from the tower to a storage tank, where it is then used to produce steam and generate electricity. Excess thermal energy is stored in the molten salt and can be used to generate power for up to 10 hours. The Crescent Dunes plant is currently in the commissioning phase.

Another innovative approach to CSP development is the combination of a high-efficiency, gas-fired combined-cycle plant together with a solar thermal steam generator, which creates a new power generation class: the integrated solar combined cycle (ISCC). The high-efficiency gas turbine can be used as a backup for the solar power when the sun is not shining. With the solar contribution, natural gas consumption can be reduced, lowering the environmental footprint of the plant. At times of high demand, the solar steam can boost electricity production while sharing the same plant equipment, infrastructure, and grid access. Alstom and BrightSource are partnering to develop and build ISCC power plants. The two leaders in their field with their respective expertise can offer a plant with optimum performance, providing reliable and economical solar power. This partnership has led to the development of the 121 MW Ashalim solar thermal project, which is expected to supply 320 gigawatt hours (GWh) of electricity annually into Israel's grid when it is completed in 2017.

## Hydropower

Hydropower is the most commercially mature renewable power technology and accounts for the

### GE's Role

As one of the world leaders in hydropower, the largest source of renewable energy on the planet, Alstom has been leading the way for more than 100 years, having installed more than 450 GW of turbines and generators—around 25 percent of the total global hydropower capacity. By leveraging Alstom technology, GE now offers unique hydro solutions to optimize assets, from single components to full turnkey solutions.



|                                   |                                   |                                                |
|-----------------------------------|-----------------------------------|------------------------------------------------|
| <b>37<sub>GW</sub></b>            | <b>1,055<sub>GW</sub></b>         | <b>16%</b>                                     |
| 2014 Global<br>Capacity Additions | 2014 Global<br>Installed Capacity | 2014 Share of Global<br>Electricity Generation |

### Recent Innovations

Alstom has pioneered hydropower innovations in the past with new solutions such as hydrostatic water guide bearings, silt abrasion protective solutions, oblique elements in the rotor and stator, and variable speed generations.

### Future Innovations

New innovations from GE will continue to make hydropower increasingly flexible, efficient, and reliable over time.

largest amount of renewable energy capacity and generation. Hydropower accounts for nearly two-thirds of all renewable energy capacity and nearly three-fourths of all renewable energy generation. Hydroelectricity offers a high level of reliability with proven and flexible technologies operating at high efficiency with low operating costs and large storage capacity.

Alstom has been a driving force behind global



hydropower for 125 years. Alstom has installed more than 450 GW of turbines and generators—around 25 percent of the total global hydropower capacity. By leveraging Alstom’s experience and global network, GE offers unique hydro solutions based on project-specific, cutting-edge, and digital technologies to deliver the greatest value to customers. Alstom is able to provide choices for the entire value chain of a hydropower plant, from equipment to services for new power plants and installed base, with a portfolio that includes all turbine and generator types including fixed and variable speed. The flexibility and the efficiency of Alstom technologies have been central to many record-breaking hydropower plants including Three Gorges in China (9,800 MW), La Grande in Canada (7,843 MW), and Itaipu in Brazil (7,000 MW).

There has been an uptick in hydropower development globally in recent years, as total installed capacity has grown by nearly 20 percent in the last five years. The rise has been particular in emerging markets where hydropower offers not only clean energy but also provides water services and energy security, and facilitates regional cooperation and economic development. Continued market growth is expected in countries with high rates of electricity demand growth and favorable hydropower sources like China, Brazil, and India. In North America and Europe, there is growing demand for refurbishments of power plants to increase their efficiency and power output, and improve their environmental performance.<sup>25</sup>

Increasing hydropower flexibility will occur as a result of new innovations that will contribute to better balancing the energy mix as the penetration of intermittent renewables continues to increase. Alstom has pioneered hydropower innovations in the past with new solutions such as hydrostatic water guide bearings, silt abrasion protective solutions, oblique elements in the rotor and stator, and variable speed generations.

### GE’s Role

Alstom is a market leader in dedicated biomass co-firing and installation. Alstom’s solutions allow customers to maximize the efficient use of biomass in power generation with our integrated solutions for biomass preparation. In addition, GE Jenbacher reciprocating engine cogeneration technology enables customers to realize the maximum economic and ecological benefits available from utilizing biogas for power generation.



|                                   |                                   |                                                |
|-----------------------------------|-----------------------------------|------------------------------------------------|
| <b>4<sub>GW</sub></b>             | <b>93<sub>GW</sub></b>            | <b>2 %</b>                                     |
| 2014 Global<br>Capacity Additions | 2014 Global<br>Installed Capacity | 2014 Share of Global<br>Electricity Generation |

### Recent Innovations

Jenbacher efficiency improvements have continued to lower the cost of biogas electricity generation.

### Future Innovations

New biomass innovations from Alstom will continue to make biomass projects increasingly flexible, efficient, and reliable over time.

Further in the hydropower space, GE is at the technology forefront for developing tidal energy both in tidal lagoon and tidal streams. As the technology partner both for the Swansea Bay tidal lagoon in the UK and Paimpol-Bréhat tidal array in France, GE is providing the technologies necessary to unleash the massive potential of tidal energy.

### Biopower

Biomass is a commercially and technically mature renewable energy technology that continues to experience gradual innovation and market expansion. Biopower is a renewable energy source using



organic materials. These include wood and wood wastes; agricultural wastes and crops produced for use as biofuels; and bio-derived fuels, including municipal solid waste, refuse-derived fuel, sewage sludge, and animal waste. Alstom is a leader in biomass. Alstom solutions allow customers to maximize the efficient use of biomass in power generation with our integrated solutions for biomass preparation. Alstom's wide range of experience includes burning all types of fuels in our boilers, including biomass.

In addition to biomass, the use of biogas to generate electricity is another promising renewable energy solution. Disposal and treatment of biological waste represents a major challenge for the waste industry. For a wide range of organic substances including agriculture, foodstuff, or feed industries, anaerobic fermentation is a superior alternative to composting. Biogas-fueled gas engines improve waste management while maximizing the use of an economical energy supply. Jenbacher cogeneration technology enables customers to realize the maximum economic and ecological benefits available from utilizing biogas for power generation.

## Geothermal

Geothermal energy is a 100-year-old energy source that is commercially and technically mature. Geothermal development occurs in areas of naturally occurring water or steam with sufficient rock permeability. Geothermal electricity generation reached 83 TWh in 2014, and 676 MW of new geothermal power generating capacity was completed in 2014, bringing total global capacity to 12.8 GW.

Alstom is a global leader in steam turbine technology with more than 100 years of experience in manufacturing, delivering, installing, and servicing steam turbine generator sets from 5 to 1,800 MW for a wide range of applications, including geothermal.

### GE's Role

Alstom is a global leader in steam turbine technology with more than 100 years of experience in manufacturing, delivering, installing, and servicing steam turbine generator sets from 5 to 1,800 MW for a wide range of applications, including geothermal.



**676<sub>MW</sub>**

2014 Global  
Capacity Additions

**13<sub>GW</sub>**

2014 Global  
Installed Capacity

**<0.1%**

2014 Share of Global  
Electricity Generation

### Recent Innovations

The development of low-cost, reliable solutions for geothermal applications around the world

### Future Innovations

Geothermal innovation will continue to advance incrementally through the end of the decade as researchers explore the feasibility of alternative technologies to exploit hydrothermal resources such as supercritical fuels, and co-produced hot water in gas and oil wells.

Alstom pioneered the commercial development of geothermal power in New Zealand in the 1950s. Today, Alstom offers an extensive portfolio of solutions for geothermal applications that are grounded in technologies that have been proven in geothermal applications worldwide. For the most challenging geothermal applications, Alstom is able to tailor solutions to take account of aggressive steam conditions.

Geothermal innovation will continue to advance incrementally through the end of the decade as researchers explore the feasibility of alternative technologies to exploit hydrothermal resources



such as supercritical fuels, and co-produced hot water and gas and oil wells.

## Ocean

Ocean energy is used to describe all forms of renewable energy derived from the sea, including wave energy, tidal energy, and ocean thermal energy conversion (OTEC). Tidal stream technology draws on the power of fast currents generated where local geography constrains movement of ocean masses. As water is 800 times denser than air, there is tremendous potential for power extraction. Alstom has developed leading tidal power technologies to tap into this reliable and predictable energy source. Tidal power is a potential growth area, with a global potential of up to 100 GW installed capacity. Being a fully predictable renewable energy source, tidal power has the potential to contribute significantly to the future energy mix of many countries wanting to benefit from renewable, low-carbon forms of electricity generation.

### GE's Role

Tidal power is a potential renewable energy growth area, with a global potential of up to 100 GW. Alstom has developed leading tidal power technologies to tap into this reliable and predictable energy source.



### Recent Innovations

Alstom offers an efficient, cost-effective, and easy-to-maintain tidal technology.

### Future Innovations

Continued development of a cutting-edge, low-cost retrievable subsea hub to connect tidal turbines to the grid in a reliable and cost-effective manner



# III. RENEWABLE ENERGY ECONOMICS

As a result of a decade of accelerated innovation, the cost of renewable power technologies has fallen to a level that has brought many of them within the range of economic competitiveness in key markets across the globe. In some locations, renewable power technologies like wind and solar PV can generate electricity at rates that are economically competitive with wholesale and retail rates, respectively. Furthermore, additional technology innovations are on the horizon that promise to bring renewables into full competitiveness on an unsubsidized basis within the next decade. The renewable energy transition has begun and will continue to accelerate over the next decade, driven by increasingly favorable renewable power economics.

Leading financial advisory and asset management firms like Lazard, global energy consultancies such as Bloomberg New Energy Finance (BNEF), governmental energy information agencies such as the US Department of Energy (DOE), and intergovernmental organizations like the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) all agree that renewable power is economically competitive in many locations today as a result of rapid innovation that has driven down costs over the last decade.

## Renewable Energy Cost Competitiveness

BNEF offers a clear analysis of changes in the levelized cost of electricity (LCOE) for renewables over the last five years.<sup>26</sup> According to BNEF's assessment, the costs of generating electricity

via onshore wind turbines and crystalline silicon PV systems have fallen by some 15 percent and 53 percent, respectively, since the third quarter of 2009. This has sharply improved the competitiveness of these generation sources compared to conventional options such as power stations burning coal, gas, or diesel; or nuclear reactors. An increasing number of wind and solar projects are now being built without any subsidy support. Latin America, the Middle East, and Africa are in the vanguard of this trend.<sup>27</sup> The net result, according to BNEF, is that the cost of renewables is at or close to competitiveness with combined-cycle gas turbine and coal-fired generation.

Lazard produces an annual assessment of the LCOE of the full range of electricity generation technologies. Lazard's analysis is consistent with GE's view of the economics of electricity generation technologies. Lazard's assessment indicates that certain renewable energy technologies are cost competitive with conventional generation technologies without taking into account potential social and environmental externalities. Lazard puts onshore wind power at \$72 to \$86 per megawatt hour (MWh); utility-scale solar PV at \$70 to \$86/MWh; rooftop commercial and industrial solar PV at \$126 to \$177/MWh; and rooftop residential solar PV at \$180 to \$265/MWh without subsidies. This compares to the ranges for natural gas combined cycle and pulverized coal, which are \$61 to \$87/MWh and \$66 to \$151/MWh, respectively.



IEA agrees that renewable generation costs are increasingly competitive and expects them to decrease. According to IEA, from 2010 to 2015, indicative global average onshore wind generation costs for new plants fell by an estimated 30 percent on average while that for new utility-scale solar PV declined by two-thirds. Over 2015–2020, IEA forecasts new onshore wind costs to decline by a further 10 percent while new utility-scale solar PV declines by an additional quarter. High levels of incentives are no longer necessary for solar PV and onshore wind, but their economic attractiveness still strongly depends on the regulatory framework and market design.<sup>28</sup>

GE's own assessment indicates that wind power costs have fallen by two-thirds since 2005, dropping from as high as \$150/MWh in 2005 to less than \$50/MWh today. This analysis, like all LCOE assessments, is subject to many assumptions regarding technology costs and performance, financing, and fuel prices. However, the primary message and main trends are clear. When it comes to cost comparisons between renewables and conventional generation technologies, the game is on. Renewables are able to compete with conventional options on an unsubsidized basis in many locations. But many of these technologies are still undergoing rapid technology innovation, and costs are going to continue to decline.

*Renewables are able to compete with conventional options on an unsubsidized basis in many locations today. New innovations such as the digitization of renewable energy will continue to drive down costs.*

It is important to note that the question of renewable power economic competitiveness is a nuanced one. The focus on LCOE obscures the fact that renewables and other electric generators provide a variety of services such as energy, capacity, and regulating reserves. This value stream includes not just energy but also ancillary services, so the relative competitiveness of alternative generation technologies cannot be summarized in one LCOE value. Given their increasing capabilities in the provision of these non-energy services, it is our view that renewables are economically competitive even from this broader perspective.

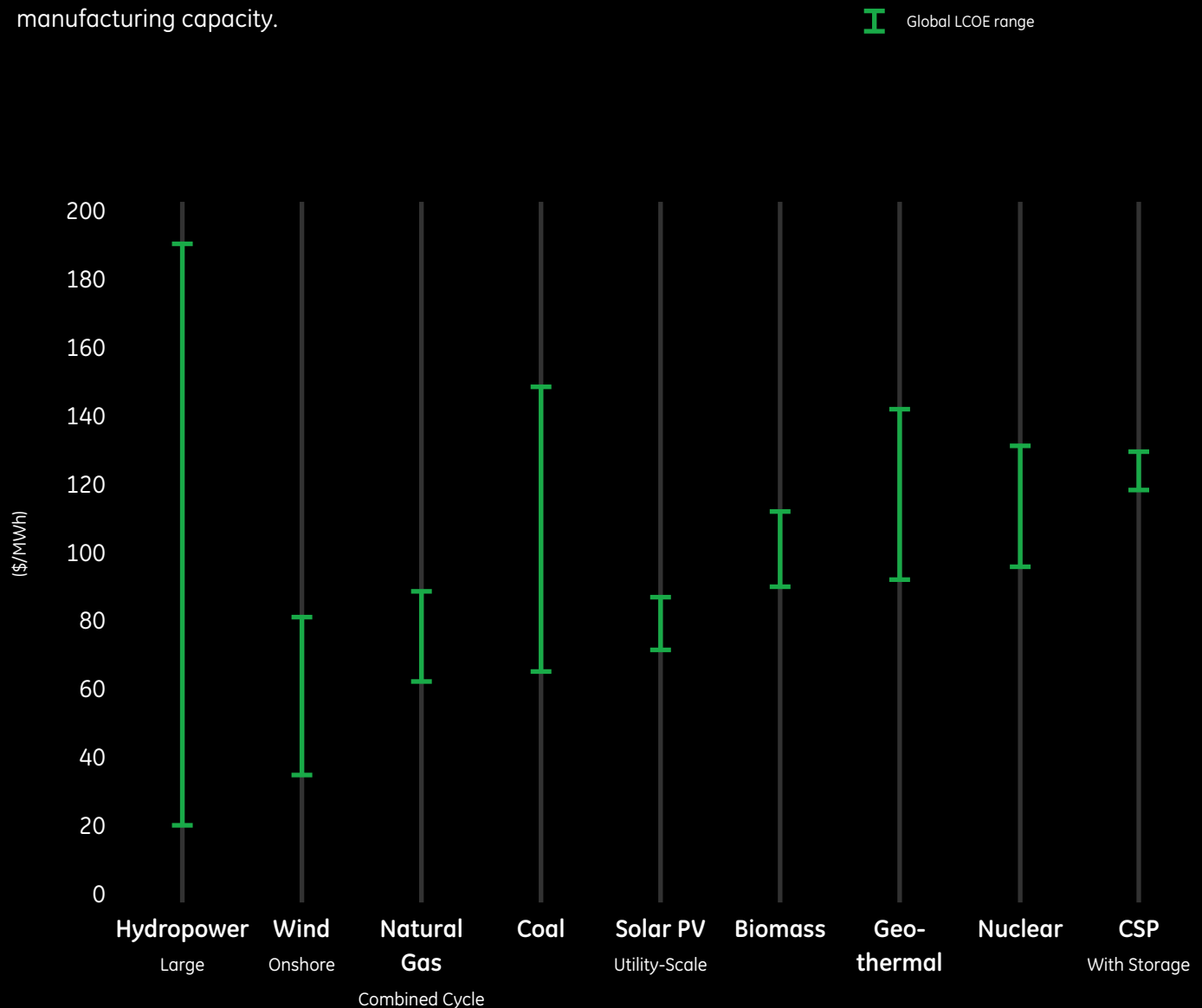
### Innovation-Led Cost Declines

Wind power costs will continue to decline over the next decade as a result of new technology innovations by GE and other wind turbine manufacturers. At the request of GE, the Joint Institute for Strategic Energy Analysis (JISEA) developed an assessment of future renewable power cost trends in order to understand the potential for wind power cost reductions.<sup>29</sup> JISEA estimated the cost of wind power in the United States, Germany, and China between 2014 and 2025.

The conclusion of JISEA's assessment is that even after a decade of progress, additional wind power cost reductions are expected over the next decade. JISEA estimates that wind power costs will decline by up to 29 percent by 2025. Future wind power LCOE reduction will be driven both by capital cost reduction and performance improvements. Between 2014 and 2015, JISEA expects wind turbine capital costs to fall from an estimated \$1,700/kW today to \$1,370/kW by 2025. Further, the JISEA analysis indicates that the capacity factor at the most favorable sites will increase from 51 to 60 percent. After a decade of innovation-led wind power cost and performance improvements, the next 10 years of innovation promise to be just as impactful.

Figure 9. In the game: Cost comparisons indicate that renewables are increasingly competitive today on an unsubsidized basis

Most renewable energy technologies have experienced significant cost reductions over the last decade. Solar PV has experienced the largest declines as a result of technical innovation and the expansion of global manufacturing capacity.



**Source:** Frankfurt School-UNEP Centre/Bloomberg New Energy Finance, "Global Trends in Renewable Energy Investment 2014," Frankfurt School of Finance & Management.





JISEA's analysis highlights the dramatic reduction in solar PV module prices by module type and country. The JISEA data shows module prices for crystalline silicon modules in Germany falling from roughly \$2.50/W in 2009 to less than \$1/W by 2014. JISEA's assessment indicates that the cost of crystalline modules decreased 75 to 80 percent over the same period. Unlike wind power, reductions in solar PV costs have been driven by more significant investment in the supply chain and greater economies of scale. However, solar PV has also experienced significant technology improvements over the last decade. The average efficiency of commercial silicon modules has improved in the last 10 years by about 0.3 percent per year, reaching 16 percent in 2013. The best-performing commercial crystalline silicon modules offer efficiencies of 21 percent. Thin film modules also offer increases in efficiency reaching 15 percent.<sup>30</sup> Additional gains have been made in manufacturing. The amount of materials, the energy consumption, and the amount of labor required to assemble modules have all been significantly reduced.

Efficiency increases and manufacturing improvements are expected to continue over the next decade, which will lead to additional reductions in the LCOE of solar PV. Based on this assumption, JISEA has estimated the solar PV LCOE for the United States, Germany, and China. JISEA expects costs to decline by up to 44 percent.

*Our analysis shows that renewables are increasingly cost competitive in many locations across the globe today, and we anticipate additional improvements as a result of continued innovation in the decade ahead.*

*—Doug Arent, JISEA Executive Director*

# IV. RENEWABLE ENERGY OUTLOOK

The pace of growth of renewable energy technologies over the last decade has been extraordinary. In 2005, global renewable energy capacity stood at 890 GW. Hydropower accounted for 90 percent of this capacity. Total renewable energy generation was 3,300 TWh, about 20 percent of total global electric generation. Now fast-forward to 2014. By the end of that year, renewable electric capacity had jumped to over 1,700 GW and generation increased to 5,500 TWh. That's a near doubling of capacity and a 65 percent increase in generation in a decade. Wind, hydropower, and solar PV additions amounted to 311, 289, and 171 GW, respectively.

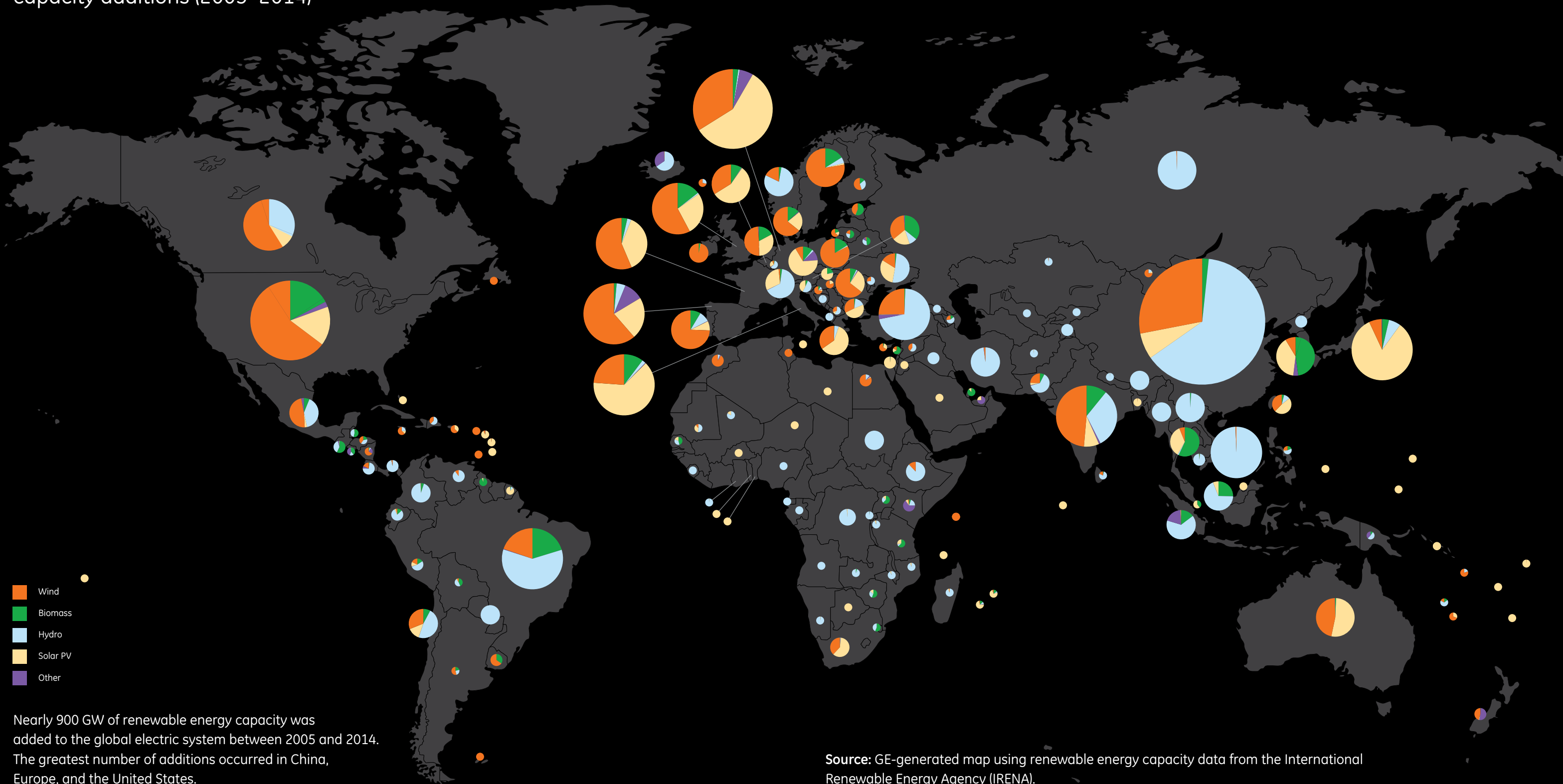
The increase was distributed across geographies. China accounted for 45 percent of the additions, Europe was responsible for 23 percent, the United States accounted for 9 percent, and the remaining amount was spread out across the globe. Not only was this a period of rapid renewable energy growth, it was also the beginning of the globalization of renewable energy as investment, capacity, and generation spread from Europe and North America to the rest of the world.

As a result of the rapid addition of renewable energy technologies to the global electric system, the world is now transitioning to a more diverse portfolio of fossil fuel, nuclear, and renewable energy technologies; both centralized and distributed generation sources will work in unison to deliver reliable and low-cost power with a reduced environmental footprint. Renewable energy is compatible with existing fossil fuel and nuclear power technologies,

and, in many cases, the addition of renewables fortifies national electric systems, making them more robust and resilient.

*Renewable energy is compatible with existing fossil fuel and nuclear power technologies, and, in many cases, the addition of renewables fortifies national electric systems, making them more robust and resilient.*

Figure 10. Global renewable power capacity additions (2005–2014)







The future growth of renewables will depend upon the rate of growth of electricity consumption around the world and the increasing desire by customers, utilities, and policymakers to increase the use of renewable energy. Increases in electricity consumption will require the addition of new sources of electricity, both renewable and nonrenewable, to meet growing demand. Global electricity consumption will grow at an average annual rate of 2.5 percent between 2014 and 2020, increasing from 21,900 TWh in 2014 to 25,435 TWh by 2020. That's a 16 percent increase in global electricity consumption over this period. The largest growth on an absolute basis is expected to occur in China, the Middle East and Africa, and India.

The increase in electricity consumption, combined with renewable energy support policies and the increasingly attractive economics of renewable energy, will result in the continued growth of renewable energy capacity through the end of the decade. GE estimates that another 730 GW of renewable energy capacity will be added between 2015 and 2020. Renewable energy capacity additions will continue to account for over half of the total global electric power capacity additions between 2015 and 2020.

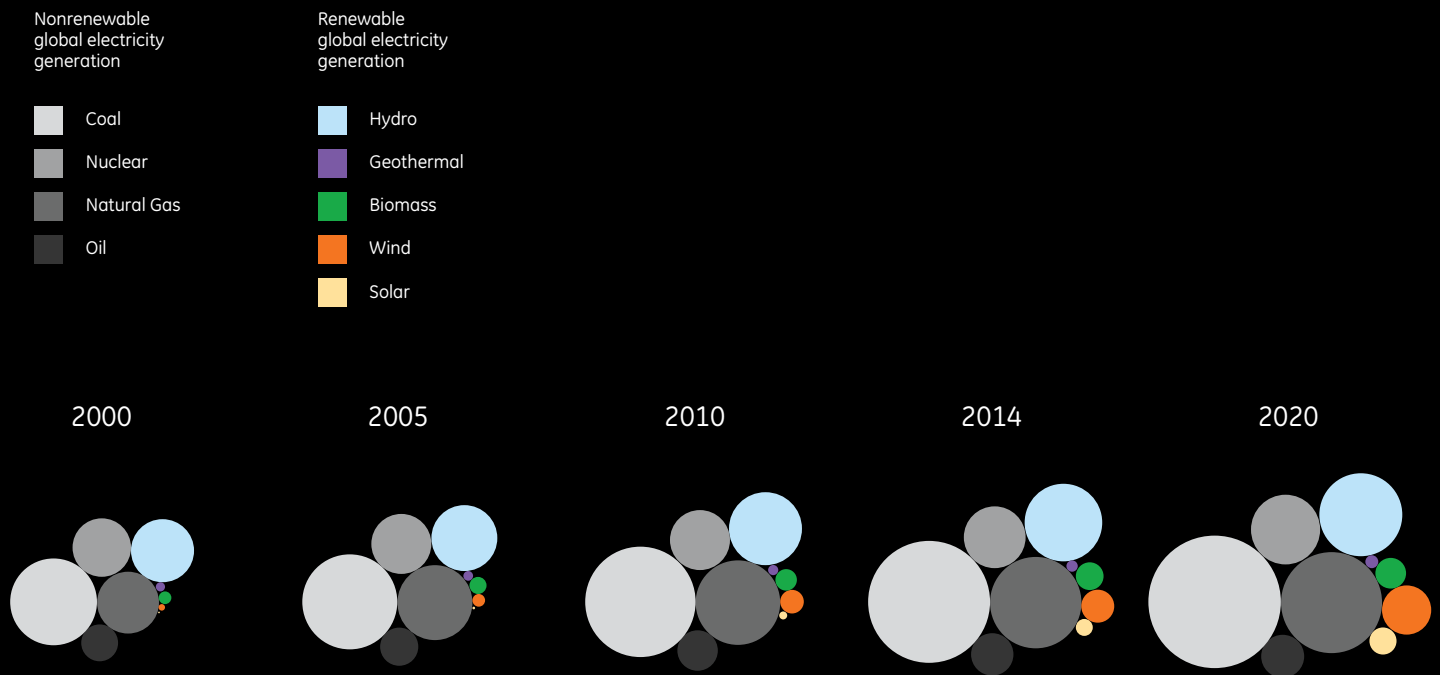
As with the last decade, hydropower, wind power, and solar PV are expected to account for 95 percent of these additions. Wind power, in particular, is expected to experience strong growth, with the potential to increase global installed capacity between 80 and 100 percent over the next five years. As a result of these additions, renewable energy generation will grow from 5,500 TWh in 2014 to 7,300 TWh in 2020, a 33 percent increase. This will increase renewable energy's share of total global electricity generation from 22 percent in 2014 to 25 percent by 2020. Carbon dioxide emissions from electricity generation will be 13 percent lower in 2020 than they would otherwise be without non-hydro renewable power technologies in the portfolio.

Figure 11. In the mix: Global electricity generation by source (2000–2020)

Renewable energy is playing an increasing role in the global electric power system over time. Renewable energy generation grew from 2,820 to 5,500 TWh between 2000 and 2014. GE expects renewable energy generation to grow to 7,300 TWh by 2020.

# 7,300

TWh renewable energy generation by 2020



**Source:** GE estimates using historical renewable energy capacity data from the International Renewable Energy Agency (IRENA).



# V. ENABLING THE TRANSITION

Continued innovation through the end of the decade will drive large amounts of renewable energy investment and capacity through the end of the decade. However, the path forward contains both challenges and opportunities. First, stakeholders must work together to coordinate and integrate electricity planning, develop rules for market evolution that enable system flexibility, expand access to diverse resources, and improve system operations.<sup>31</sup> In order to accommodate the increasing levels of variable renewable energy, both demand- and supply-side technologies within the electric system must become increasingly flexible. Greater levels of deployment and utilization of the existing grid-friendly capabilities of renewables will be required. Technology innovations, like more sophisticated methods of forecasting the wind and sun, and cost-competitive energy storage solutions, will be needed to allow renewables to become more predictable and to better manage variability. And finally, the Industrial Internet must be fully leveraged to enable greater control and coordination across the grid.

## Grid Integration

The primary challenges of integrating renewable energy technologies into the electric grid are related to uncertainty and variability. Wind and solar PV generation vary depending on whether or not the sun is shining or the wind is blowing, and at what intensity. This occurs across several timescales from minutes to seasons, and actual output is often different from forecasted output. Further, wind and solar PV incur opportunity costs

to the system when they are used at power levels different from what's currently being produced from the available wind and solar generation at a given point in time.

As the penetration of renewable energy technologies increases, system operators will have to deal with this uncertainty and variability. GE's Energy Consulting team has developed insights that will enable grid operations managers to implement technology and operational strategies that will become important in jurisdictions with increasingly high levels of variable generation over time.

GE Energy Consulting's findings from conducting major renewable integration studies indicate that some of the key impediments to greater renewable energy penetration are lack of transmission; lack of electricity control area cooperation; market rules that create contract constraints; distributed energy resources that are unobservable, uncontrollable, and do not support grid reliability; as well as current inflexible system operation strategies during light-load and high-risk periods.

GE's analysis also provides insights on the keys to successful renewable energy integration: more accurate renewable energy forecasting, more flexibility from the surrounding fleet of thermal generators, more strategic siting of renewable energy technologies, and more demand-response flexibility. These insights identify the critical areas where key innovations must be developed and implemented to enable the successful integration of renewable energy.

## Grid-Friendly Renewables

Over the last decade, GE and others have made innovations to make wind power a good grid citizen. Power controls have advanced so that operators can exercise more control flexibility to avoid curtailment and realize greater revenue opportunities. Voltage controls have improved so that renewables can connect to weak grids with greater success. Utility trust has been increased as a result. Ride-through controls have advanced to stabilize the grid during disturbances and provide enhanced grid support.

These are the successes of the last decade, but greater utilization of these capabilities and more advances are needed to enable an even greater amount of renewables to participate in the global electric power system. This includes both hardware and software innovations designed to enable renewable energy technologies to mimic their nonrenewable counterparts more successfully by providing even more reliable, dispatchable power and ancillary services.

## Energy Storage

For the last 100 years, energy storage in the electric sector has been limited to hydropower storage. Hydropower is a strong complement to variable renewable energy technologies and will continue to play an important role. However, if renewable energy technologies are going to successfully increase their share of global electricity generation, then additional energy storage options will need to be part of the solution. Energy storage solutions can provide backup power to homes, businesses, or utilities; cut peak demand charges; provide firm peak capacity to the grid; and provide frequency regulation and better coordination between distributed generators and the utility grid. The availability of energy storage will also

facilitate the growth of renewables by reducing variable spikes or troughs in power generation and voltage, which could lead to grid instability at higher penetration rates.

Recent developments have demonstrated the ability and capability of energy storage technologies to facilitate the growth of renewable energy. Energy storage solutions are increasingly economic and provided in a variety of renewable energy applications. GE's Brilliant Wind Turbine is an example of variable renewable energy integrated with battery technologies in order to provide a more grid-friendly source of electricity. Near-term energy storage applications include commercial-scale battery solutions coupled with intelligent software and predictive analytics, and residential applications that include solar PV packaged with battery solutions.

Current's energy storage solutions help customers provide flexibility across the grid by combining GE's expertise in plant controls, power electronics, and a variety of battery and enclosure technologies—all backed by GE performance guarantees. By focusing on full system performance rather than the component pieces, GE helps customers match power production with demand in real time and will develop the right technology to fit each site's specific needs. GE has more than 100 years of experience powering the world and now through Current, is poised to continue leading in the energy storage technology evolution.

## Digital Renewable Energy

The advancement of technologies to make the grid and its technologies more flexible to enable higher levels of renewable energy penetration is a critical part of enabling the renewable energy transition. This includes hardware as well as software solutions. Flexibility depends upon communication advances that enable greater control and



coordination across the grid. There is a need for high-speed digital monitoring of the grid in order to check the status of the transmission system and its elements in real time. This information will enable automatized responses and provide information for manual responses.

Technologies like GE's Grid IQ™ system have a role to play here. Grid IQ Solutions as a service delivers subscription-based hosted smart grid service packages designed to leverage GE's breadth, experience, and smart grid technology to shift integration and financial and deployment risks away from the utility and provide a cost-effective smart grid solution. The offering utilizes GE-owned smart grid software and hardware technologies and strategic partnerships to provide meters and metering services, advanced metering infrastructure, meter data management, a prepayment outage management system, interactive voice response, and a geospatial information system as pre-integrated standard packages for faster deployment at a low upfront cost and with low utility risk.

Virtual power plants (VPPs) will also have an increasing role to play in the renewable energy transition. A VPP is a group of distributed power technologies that are aggregated and operated in unison by a centralized control system powered by the Industrial Internet. Centralized control and operation extends the capabilities of individual distributed power units by enabling groups of grid-connected plants to deliver electricity to the transmission network in unison during periods of peak demand. A VPP could serve as a substitute to a single large power plant. Further, individual distributed power units would be more flexible and quicker to react to fluctuations in electricity demand. VPPs also have the potential to coordinate distributed power system operation with options related to electricity demand, such as demand response and other load-shifting approaches.

Today's distributed power digital control systems have already enabled operators to remotely monitor and control all aspects of power plant operation. This capability has enhanced the distributed power value proposition, and it is part of the driving force behind the rise of distributed power. However, this is only the tip of the iceberg. Tomorrow's control systems will open the door to an extended range of capabilities that will further enhance the attractiveness of distributed power. VPPs will enable a fleet of distributed power systems to operate in a coordinated manner to facilitate fleet-wide optimization. VPPs will serve as a virtual complement to large central power plants by providing both electricity supply and coordinating demand-side options. The VPP and the Industrial Internet will propel distributed renewable energy technologies to new heights.

### Renewable Energy Commitments

Corporations around the world have often faced barriers when they attempted to purchase renewable energy directly. In many cases, utilities didn't have the ability or desire to supply renewable energy to meet customer demands. Over the past several years, corporations that have a demand for clean energy have taken the initiative by calling for electric utility policy changes and making direct investments themselves in renewable energy.

In July 2014, US corporations General Motors, Hewlett-Packard, Wal-Mart, and others signed a corporate renewable energy pledge asking utilities to make it simpler for them to buy renewable energy. More than 19 corporations signed the pledge presenting 10 TWh of electricity demand per year. In October 2014, 23 international corporations led by IKEA and Swiss Re pledged to go 100 percent renewables through the RE100 partnership. They are halfway to their goal already.

Others have committed to buy renewable energy directly. For example, Apple owns the largest private solar arrays in the United States. Their Maiden, North Carolina, data center generates about 167 kWh of electricity per year from solar and fuel cells. Google has invested \$1.5 billion in renewable energy projects globally. It purchases wind-generated power directly from farms close to its data centers and has at least seven contracts for more than 1,040 MW of wind energy. In March 2015, IBM announced a pledge to source 20 percent of its power from renewable energy by 2020. IBM has committed to contract for over 800 TWh of renewable electricity every year by 2020. By increasing the demand for renewable energy, these commitments are playing an important part in sustaining renewable energy growth and investment in the years ahead.

One area of increasing interest and use among businesses, municipalities, and schools that want to invest in renewable energy is the direct procurement of renewable energy, either through PPAs or direct ownership. Directly procuring renewable energy can help organizations that committed to renewable energy purchase clean electricity without having to route purchases through electric utilities that may or may not have renewable energy in their portfolios. All of these efforts will be important to sustain renewable energy demand moving forward.

## Financial Innovations

The renewable energy transition is characterized by an increase in the global demand and supply of renewable energy driven by innovation. The instances of technology innovation are well known and continue to improve the efficiency and economics of renewable energy technologies. However, business model innovations are proving just as critical to sustaining the surge

in renewable energy. For instance, the advent of the TPO model for solar in the United States has proven to be a successful business model innovation for alleviating some key market barriers, such as reducing upfront costs and simplifying the installation process. This model could be replicated to help reduce technology adoption barriers in other markets. New financial innovations, like yieldcos, are proving to be an invaluable source of low-cost equity for renewable energy developers.

Renewables are increasingly seen as a stable and low-risk investment by institutional funds. This has created an opportunity for institutional investors to provide capital for renewable energy projects through green bonds, which are bonds created to fund projects that have positive environmental benefits. Issuance of green bonds hit a new record of \$39 billion in 2014.<sup>32</sup>

Like yieldcos, green bonds are now spreading to new markets from their historical homes of the United States and Western Europe. For example, Brazil's development bank is developing a green bonds program for the renewable energy sector. In Indonesia and Malaysia, green sukuk (sharia-compliant Islamic bonds) are being developed to finance renewable energy projects. Yieldcos, green bonds, and additional financial innovations that are on the horizon will be required to sustain renewable energy growth moving forward.





# VI. TRANSFORMING TOMORROW

*The future may see nature harnessed in new ways—from sun, wind, and seas—who knows.*

—GE advertisement in *Scientific American* (1913)

From GE Renewable Energy to Current, GE's renewable energy portfolio is both broad and deep. With the addition of Alstom, GE now offers one of the world's most diverse portfolio of renewable energy technologies, products, and services. When combined with the built-in capability of the GE Store—the synergies that are created by the unique combination of GE businesses across global industries—the diversity of offerings and expertise in GE's renewable energy universe are vast.

Cost-competitive and environmentally sustainable power generation technologies are more than just an aspiration; they are now the reality. Over 100 years ago, GE imagined a world where humankind was able to successfully harness the sun, wind, and sea.<sup>33</sup> Thanks to continuous technology innovation, this is the world that we live in today. Let's seize this opportunity and work collaboratively to further accelerate renewable energy innovation, build new solutions, and create a truly sustainable electric power system for the planet, its people, and the world economy.

## GE's Renewable Energy Investments

GE is not just a manufacturer of renewable energy equipment and provider of software and services. GE invests in renewable energy projects and companies through GE Energy Financial Services (EFS) and GE Ventures. Renewable energy has been a strategic growth initiative at GE EFS since 2006. The unit has invested and made commitments to invest more than \$12 billion globally for projects generating power from the wind, sun, and other renewable energy sources. Among these commitments, the GE unit has committed more than \$9 billion in over 15 GW of wind and \$2.5 billion for 2 GW of solar. Geographically diversified, the projects span 17 countries and 28 states. GE EFS expects it will continue to invest more than \$1 billion annually in wind, solar, and other renewable energy projects—its fastest-growing energy sector and one that often facilitates sales of GE's energy technology. Through GE Ventures, GE also provides capital to start-ups in order to accelerate growth and commercialize innovative ideas.

## NOTES

1. Renewable energy technologies are used widely around the world for power, heat, and transportation. The primary focus of this report is renewable electric generation technologies. For more information on the current status of and future prospects for renewable energy heat and transportation technologies, see “Renewables 2015: Global Status Report” by Renewable Energy Policy Network for the 21st Century (REN21), June 2015.
2. The renewable energy capacity figures in this report were generously provided by the International Renewable Energy Agency (IRENA).
3. Palmer Cosslett Putnam, *Power from the Wind* (Van Nostrand Reinold Company: New York 1948).
4. GE estimate based on International Energy Agency (IEA) historical generation data and IRENA renewable power capacity data.
5. Bloomberg New Energy Finance (BNEF) and Frankfurt School FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, “Global Trends in Renewable Energy Investment 2015” (2015).
6. See the statement from the European Bank for Reconstruction and Development (EBRD) at <http://www.ebrd.com/news/2015/ebrd-financing-of-renewables-overtakes-thermal-power-generation.html>.
7. Assumes non-hydro renewable power generation is displacing fossil fuel generation with a carbon intensity of 1.86 pounds per kWh, which was the global average emissions rate for fossil fuel generation in 2014.
8. According to REN21 (2015), in 2005, 40 countries had implemented renewable energy support policies. By 2014, the number of countries with renewable energy policies had increased to 270. Feed-in tariffs and renewable portfolio standards (RPS) remain the most commonly used support mechanisms.
9. Jacquelin Cochran, Lori Bird, Jenny Heeter, and Douglas J. Arent, “Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience” (Joint Institute for Strategic Energy Analysis: Golden, Colorado, April 2012).
10. As quoted in the *Wall Street Journal* essay “The Power Revolutions” by Dan Yergin, published on August 21, 2015.
11. GE estimate based on IEA CO<sub>2</sub> emissions data for 2012 from IEA, “World Energy Outlook 2014” (2014).
12. GE estimate based on 2013 global water withdrawal data from the World Bank and GE’s current and future gross domestic product (GDP) estimates.
13. IRENA, “Renewable Energy in the Water, Energy & Food Nexus” (2015).
14. Jacquelin Cochran, Lori Bird, Jenny Heeter, and Douglas J. Arent, “Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience” (Joint Institute for Strategic Energy Analysis [JISEA]: Golden, Colorado, April 2012).
15. Putnam, *Power from the Wind*.
16. NASA’s experimental MOD-1 wind turbine was built by General Electric. It was installed in the mountains of North Carolina in October 1978. It was the first wind turbine in the world to achieve 2 MW of power output.
17. GE has acquired Enron Wind’s fully integrated wind power capabilities including power plant design, engineering and site selection, and operation and maintenance services.
18. Capacity factor of a wind turbine is the ratio of its actual energy output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time.
19. Global Wind Energy Council (GWEC), “Global Wind Report 2014” (2014).
20. SolarPowerEurope, “Global Market Outlook (2015–2020)” (2015).
21. GTM Research, “PV Pulse” (April 2014).
22. Camila Stark, Jacquelyn Pless, Jeffrey Logan, Ella Zhou, and Douglas J. Arent, “Renewable Electricity: Insights for the Coming Decade” (JISEA: Golden, Colorado, February 2015). Available for download at <http://www.nrel.gov/docs/fy15osti/63604.pdf>.
23. Deutsche Bank Markets Research, “Solar Industry: Crossing the Chasm” (February 2015).
24. Ibid.
25. REN21 (2015).
26. Levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per-kWh cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. LCOE is not the only method for comparing electricity generation options, but it is the most straightforward and reliable metric for head-to-head comparisons of diverse generation technologies.
27. BNEF and Frankfurt School FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, “Global Trends in Renewable Energy Investment 2014” (2014).
28. IEA, “Renewable Energy Medium-Term Market Report 2015” (October 2015).
29. JISEA (2015).
30. IEA, “Technology Roadmap: Solar Photovoltaic Energy” (2014).
31. Jacquelin Cochran, Lori Bird, Jenny Heeter, and Douglas J. Arent, “Integrating Variable Renewable Energy in Electric Power Markets” (JISEA: Golden, Colorado, April 2012).
32. BNEF (2014).
33. “The future may see nature harnessed in new ways—from sun, wind, and sea—who knows?” quotation from GE advertisement in *Scientific American* (1913).

Copyright © 2015 General Electric

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without prior written permission from GE.