Hybrid Solutions

gepower.com/hybrid

There's a way to do it better...

find it.

THOMAS EDISON
Inventor, businessman and founder of the General Electric Company

hy·brid

/'hī brid/

Noun

1. BIOLOGY: the offspring of two plants or animals of different species or varieties, such as a mule.
2. a thing made by combining two different elements; a mixture.

Adjective

1. of mixed character; *composed of mixed parts.*

Hybrids have been commonplace in the plant and animal kingdoms for millennia. Different species or varieties of organisms have been crossbred because they have desirable characteristics not found or inconsistently present in the parent individuals or populations.

**Trademark of the General Electric Company*

trends

tan·ge·lo

/ˈtanjəˌlō/

Noun

A bright red-orange *hybrid* of a tangerine and grapefruit with an unmistakable sweetness countered by a tart aftertaste (courtesy of its grapefruit ancestor). Tangelos are seedless, easy to peel and have a thick skin similar to that of oranges.

Hybrid solutions: defined

Each form of power generation has its pros and cons.

No single form of power generation is optimal in all situations. Wind and solar are intermittent but consume no fuel and emit no greenhouse gases. Natural gas-fueled generation emits greenhouse gases but it is dispatchable (i.e., has output that can be readily controlled between maximum rated capacity or decreased to zero) to help balance supply and demand. It also has a relatively low CAPEX ($/kW). Hydro power often requires dedicating significant amounts of land area but is renewable and dispatchable.

The Electric Power Research Institute created the chart below to compare the advantages and challenges of various forms of power generation technologies. Although there may be specific instances of power plants which do not align with the relative ratings below, it is a good representation of industry trends. The full comparison and underlying basis for the ratings can be found at: **http://sites.epri.com/refcard/comparison.html**

Hybrid power plants usually combine multiple sources of power generation and/or energy storage, and a control system to accentuate the positive aspects and overcome the shortcomings of a specific generation type, in order to provide power that is more affordable, reliable and sustainable. Each application is unique, and the hybrid solution that works best for a specific situation will depend on numerous factors including: existing generation assets, transmission and distribution infrastructure, market structure, and fuel prices and availability.

ELECTRICITY GENERATION *technologies*

Advantage ● ◕ ◑ ◔ ○ Challenge

Assessment of relative benefit/impact	Coal	Coal w/CCS*	Natural Gas	Nuclear	Hydro	Wind	Biomasss	Geothermal	Solar Photovoltaic
Construction cost New plant construction cost for an equivalent amount of generating capacity	◕	◔	●	○	◑	◕	◑	◔	◕
Electricity cost Projected cost to produce electricity from a new plant over its lifetime	◕	○	●	◕	◔	◕	◔	◑	◔
Land use Area required to support fuel supply and electricity generation	◑	◑	◕	●	◑	◔	○	◕	◔
Water requirements Amount of water required to generate equivalent amount of electricity	○	○	◑	○	◑	●	○	◑	●
CO_2 emissions Relative amount of CO_2 emissions per unit of electricity	○	◕	◑	●	●	●	◕	◕	●
Other air emissions Relative amount of air emissions other than CO_2 per unit of electricity	○	○	◑	●	●	●	◔	◕	●
Waste products Presence of other significant waste products	○	○	●	◔	●	●	◔	◕	●
Availability Ability to generate electricity when needed	●	●	●	●	◑	○	●	●	○
Flexibility Ability to quickly respond to changes in demand	◑	◑	●	◔	●	○	◑	◕	○

**CCS: Carbon Capture and Storage*

Source: Electric Power Research Institute (EPRI). Any statements, conclusions, summaries or other commentaries expressed herein do not reflect the opinions or endorsement of EPRI.

Hybrid solutions: defined

The possible combinations of equipment to make a hybrid power plant are extensive and limited only by the specific application and imagination of the plant designer. In its most basic sense, a hybrid power plant is comprised of three main elements:

generation sources

storage systems

shared controls

Hybrid solutions: value

According to the International Energy Agency, in 2015 the world added more renewables-based power generation capacity than all other technologies combined for the first time ever. In the same year the total global installed renewables capacity surpassed installed coal capacity. This rapid deployment of renewables is an important step toward meeting the COP21 Paris Agreement to limit CO_2 emissions. In some locations the existing grid infrastructure was not designed to handle this influx of often intermittent, and often distributed generation but other locations have been able to accommodate several GWs of renewables without significant system change.

This trend toward increasing renewables deployment is expected to accelerate over the coming decades. In its baseline New Policies Scenario the IEA predicts that by 2040 total global generation capacity will increase by more than 60% to more than 11,000 GW, and over 45% of this total will be renewables capacity.

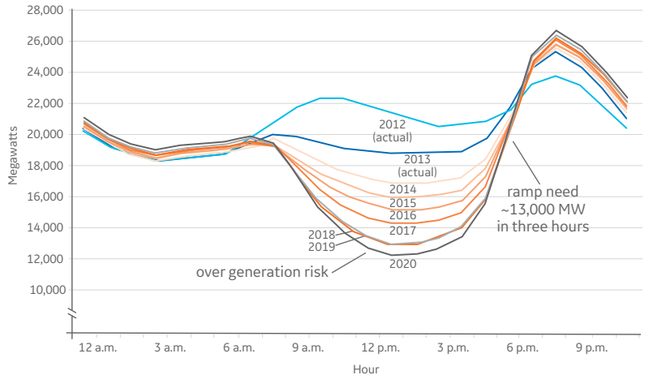
This shift to more renewables capacity combined with the other transformations in the ecosystem require new ways of thinking about the electricity system. Grid operators and system planners face many challenges including the following:

- Integration of variable and distributed generation
- Flat load growth—but faster ramps with higher peaks
- Multiple gas turbine starts per day
- Thermal fleets dispatched to minimum loads
- Increased need for operating spinning reserve
- Weak grid infrastructure
- Reducing emissions

The California Independent System Operator (CAISO) created the "Duck Curve" to demonstrate the challenges of managing a changing electricity grid as more renewables are introduced into a system that does not have enough flexible resources to ensure grid reliability. Hybrid solutions are well suited to address these challenges, and in fact, several gas turbine/battery storage hybrid systems have already been deployed in California.

TYPICAL SPRING DAY

The duck curve shows steep ramping needs and over generation risk



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A hybrid PV plus battery storage hybrid power plant stores energy generated by the PV portion and selectively discharges the stored energy. In Figure 1 below, the system is storing 100% of the solar energy and shifting it (discharging) later in the day in order to completely avoid curtailment of the solar energy. Figure 2 is an example of partial shifting approximately 30% of the solar energy to a peak demand period later in the day. In a solar firming application (Figure 3), the intent is to maintain a steady plant output at the grid point of interconnection.

Figure 1: "Full shift" solar offset fuel burn

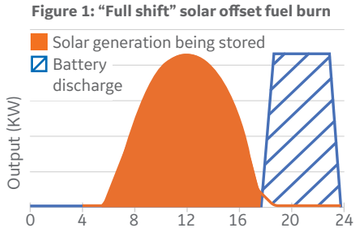


Figure 2: "Partial shift" solar to peak

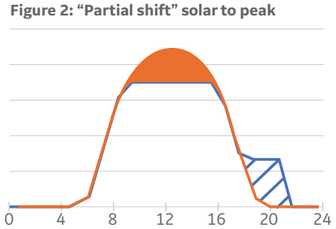
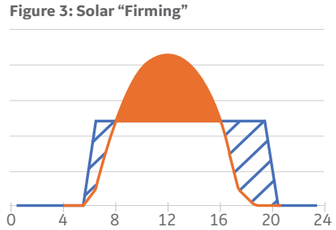
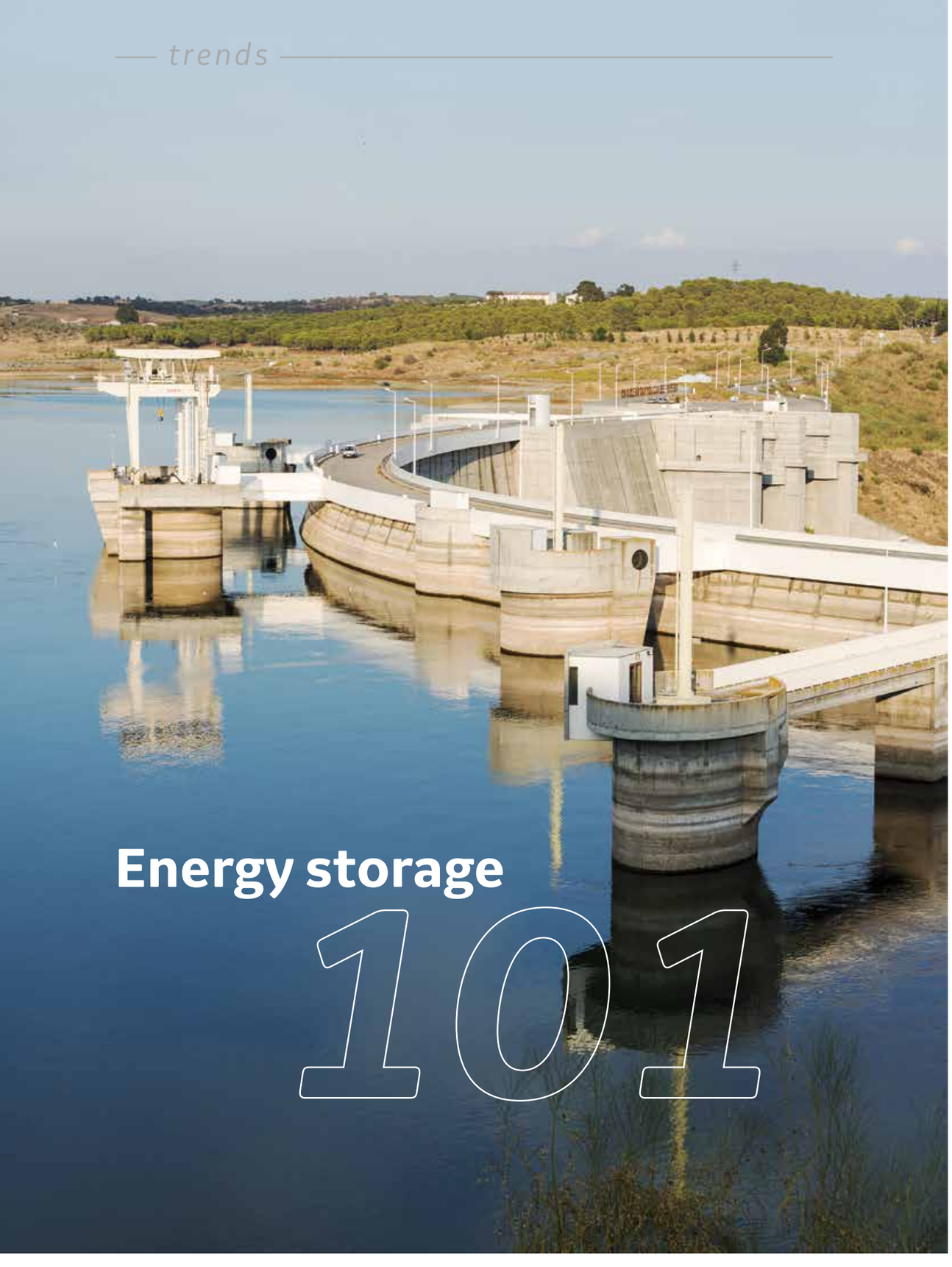


Figure 3: Solar "Firming"



TYPICAL USE CASES

Use Case	Typical Hybrid Solutions	Typical Outcomes
Grid Autonomy (Micro/Offgrid)	• Solar PV + BESS Storage + Reciprocating Engine	**Access to electricity everywhere** • Increase the availability of electricity to under-served regions or regions with no access • Increase grid stability in weak grid locations • Reduce fuel costs by displacing some of the fossil fuel with solar PV • Portable – can be relocated if needs change
Dispatchability of Renewables	• GT + Wind/PV + Storage • Recips + Wind/PV + Storage • Wind + Storage • Solar + Storage • Wind + Solar + Storage • Hydro + Solar • Wind Integrated Solar Energy	**Baseload generation with renewables** • Reduce or eliminate curtailment by storing excess supply for use during periods of low supply • Increase the annual energy production through complementary supply of wind and solar during different times of the day • Reduce system levelized cost of electricity (LCOE) by optimizing the mix of renewables and thermal supply • Increase the predictability and dispatchability of renewables to enable firm Power Purchase Agreement participation • Improve matching of production and consumption
CAPEX & OPEX Improvement	• GT/CCGT + Storage • Solar PV + BESS storage + Reciprocating Engine	**Using existing infrastructure and O&M capabilities** • Reduced CAPEX by sharing plant electrical evacuation equipment • Reduce O&M costs through shared services • Reduce fuel consumption and CO_2 emissions by displacing fossil generation • Reduce system LCOE by optimizing the mix of renewables and thermal supply
T&D Deferral	• GT/CCGT + Storage • Wind + Storage • Solar + Storage • Wind + Solar + Storage • Hydro + Solar • Solar PV + BESS Storage + Reciprocating Engine	**Storing energy to reduce stress on the grid and reduce the need for new T&D** • Reduce T&D CAPEX by shifting generation to meet peak loads • Increase T&D expected lifecycle because of lower peak utilization • Enable more distributed energy resources in the system • Reduce peak demand charges by smoothing the demand profile and avoiding load shedding
Peak Shaving, Ramping, Time Shifting	• GT/CCGT + Storage • Wind + Storage • Solar + Storage • Wind + Solar + Storage • Hydro + Solar	**Increasing revenue opportunities** • Increase revenue through improved ability to arbitrage wholesale power prices • Increase revenue through increased participation in multiple ancillary services markets



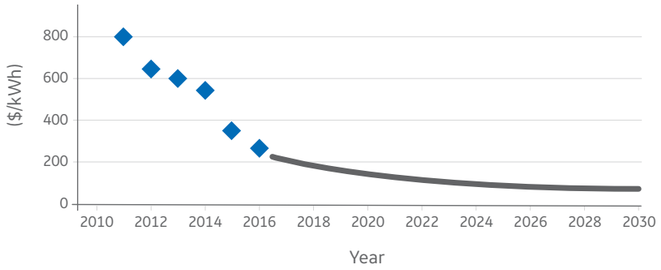
Energy storage 101

The most prevalent form of energy storage today, in terms of installed capacity, is pumped hydro storage. This form of storage has its origin in the first dams that were put across streams in order to provide steady and reliable power for a water wheel or similar device. In a pumped hydro storage facility, water is pumped uphill into a reservoir when excess generating capacity is available (and electricity prices are low), and then allowed to flow downhill through turbines when demand is higher (and electricity prices are higher). The round trip efficiency of this type of system is approximately 80%. There are more than 160 GW of pumped storage installed globally today, and the first is believed to be a 1 MW facility built at Schaffhausen, Switzerland. The largest currently in operation is a 3 GW facility in Bath County, Virginia, USA.

Other forms of energy storage in use today include batteries, capacitors, molten salt and other thermal storage systems, flywheels, compressed air energy storage systems, and others. These have been deployed with varying success around the world. The primary drawback to most of these storage systems has been cost, but today Li-ion batteries and pumped storage represent the most commercially feasible forms of storage.

In its New Energy Outlook 2017, Bloomberg New Energy Finance estimates that the cost of Li-ion battery packs has fallen from $1,000/kWh in 2010 to $273/kWh in 2016. They forecast Li-ion battery pack costs will fall to approximately $73/kWh by 2030 due to several factors including: technology improvements, manufacturing scale, and market competition among suppliers. It is this exponential reduction in costs that have opened up new opportunities for battery energy storage systems at scale.

LITHIUM-ION BATTERY PRICE FORECAST



Source: Bloomberg New Energy Finance

TYPICAL GRID-SCALE STORAGE APPLICATIONS

Storage Type	Discharge Time	Technology	Application(s)	Typical Storage Capacity
Short-term	Seconds to minutes	Li-Ion Battery Energy Storage System (BESS)	Grid Ancillary Services	500 kWh – 40 MWh
		Li-Ion BESS with AC BUS connected for load ramping or grid stabilization	Off-Grid/ Weak Grid	500 kWh – 2.5 MWh
Short-term	Minutes to hours	Li-Ion BESS modular enclosures or purpose-built buildings	Renewables integration, grid balancing services, Off-Grid/Weak-Grid	500 kWh – 50+ MWh
Mid-term	Hours to days	Li-Ion BESS modular enclosures	Renewables integration, grid balancing services, Off-Grid/Weak-Grid, energy shifting, peak management	500 kWh – 1,200+ MWh
		Fixed and variable speed pumped hydro storage	Renewables integration, grid balancing services, Off-Grid/Weak-Grid, energy shifting, peak management	up to 6 GWh/d

Battery storage

WORLD'S FIRST *battery*

The oldest electricity storage device is believed to date from approximately 200 BC. It was discovered near Baghdad, Iraq, and is located at the Iraq National Museum. Experiments have shown that this clay pot, fitted with a copper electrode and filled with vinegar or a similar acid, could generate between 1.5 and 2 volts. The purpose of this battery remains a mystery.

In the late 18th and early 19th centuries, electrical pioneer Alessandro Conte di Volta investigated the effects obtained when different metals are placed in certain salt solutions. In 1800 he designed a device that had alternating discs of zinc and copper separated by cardboard with a brine solution as the electrolyte. His experiments are the foundation for current battery energy storage systems.

BATTERY ENERGY STORAGE systems are typically configured in one of two ways, a *power* configuration or an *energy* configuration, depending on their intended application. This is accomplished by adjusting the ratio of inverters to batteries in the system.

A simple way to envision this is to imagine a bathtub; the volume of water in the bathtub would represent the batteries and the drain(s) in the tub would represent the inverter(s). For a fixed level in the bathtub, several drain lines can be incorporated, resulting in a rapid discharge (a power configuration), or a single drain line can be incorporated resulting in a slower discharge (an energy configuration). In each case, the system has the same amount of water (stored energy in the battery), but the discharge rate is varied.

$$C_{rate} = \frac{\text{Megawatts}}{\text{Megawatt–hours}}$$

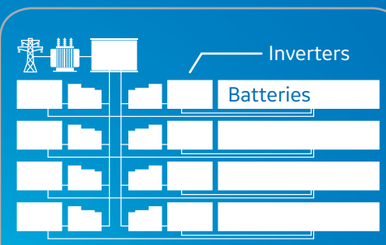
Battery Discharge Capability

power CONFIGURATION

In a **power configuration** the batteries are used to inject a large amount of power into the grid in a relatively short period of time. There is a high inverter to battery ratio required to accomplish this. A typical application would be to simulate a turbine ramp up for frequency regulation, spinning reserve or black start capability.

Bathtub analogy: Several drains for **RAPID CHARGE/ DISCHARGE**

- High Inverter/Battery Ratio
- Fast discharge
- C rate of MW/MW-hr > 1
- Low cost/MW
- Requires more space than an energy configuration
- Typical applications include spinning reserve, black start, fast start



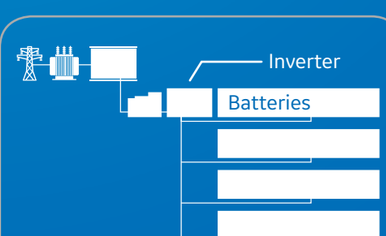
VS.

energy CONFIGURATION

In an **energy configuration** the batteries are used to inject a steady amount of power into the grid for an extended period of time. This application has a low inverter to battery ratio and would typically be used for addressing issues such as the California "Duck Curve" in which power demand changes are occurring over a period as long as several hours, or shifting curtailed PV production to a later time of the day.

Bathtub analogy: Single drain for **SLOWER CHARGE/ DISCHARGE**

- Low Inverter/ Battery Ratio
- Slow discharge
- C rate of MW/MW-hr < 1
- Low cost/MW-hr
- Requires less space than a power configuration
- Typical applications include "Duck Curve," power makeup, energy shifting, curtailed energy capture



solutions

lab·ra·doo·dle

/ˈlabrəˌdo͞odl/

Noun

Labradoodles are a *hybrid* mix of the Labrador Retriever and Poodle, bred to combine the outgoing, happy personality of the Labrador with the non-shedding coat of a Poodle.

GE's hybrid portfolio

Designed to be scalable, customizable and flexible to deliver a wide range of Electricity Value Network (EVN) solutions

GE has more than 125 years of integrating the latest innovations in electricity generation and delivery. Approximately one-third of the electricity generated in the world uses GE equipment. GE's hybrid portfolio can be customized and scaled for specific customer or system needs.

OUR HYBRID PORTFOLIO INCLUDES:

Building Blocks

- Battery Energy Storage Solutions (BESS)
- Industrial Internet Control System
- Wind Turbines, Hydro Turbines, Gas Turbines, Steam Turbines, Reciprocating Engines, Solar PV

Hybrid Systems

- Wind Integrated Solar Energy (WiSE)
- Hydro Pumped Storage
- Simple Cycle Gas Turbine + Battery
- Combined Cycle Gas Turbine + Battery
- Gas Engine + Renewables + Battery
- Containerized Packages

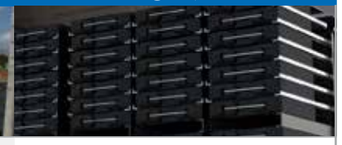
HOW IS GE DIFFERENTIATED?

GE provides wing-to-wing hybrid solutions from upgrading and improving the capabilities of an existing facility, to incorporating hybrid capabilities into a new generation facility or transmission and distribution network. Depending on the specific needs of a customer, GE can offer:

- Plant and grid feasibility studies
- Financing solutions
- Plant and equipment design
- Wind, hydro and solar forecasting via digital wind, digital hydro and digital solar farms
- Hardware and software solutions
- Turnkey construction
- Operations and maintenance
- Remote monitoring and diagnostics via Predix*
- System integrated, predictive operation using Predix

*Trademark of the General Electric Company

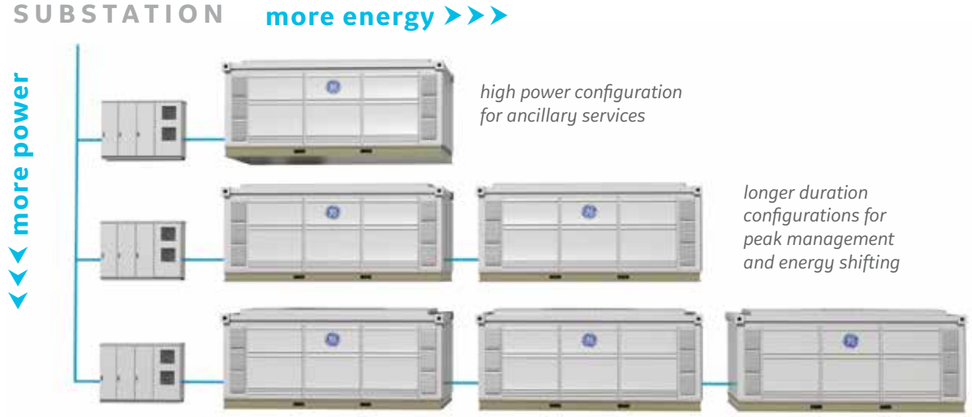
	Solar	Wind	Off Grid Electrification	Hydro
				
SOLUTIONS	Solar + BESS Solar + Diesel + BESS	WiSE Wind + BESS Wind + Diesel + BESS	Containerized package of PV + BESS + Recip, from 15kW to 1MW For commercial and industrial applications	Hydro + PV Pumped Storage Intermittent wind or PV & PSP
VALUE PROPOSITION	• Storage integration for dispatchable solar • Bulk, long term storage possible • Enhanced capacity factor • Well suited for high solar resource countries	• Lower O&M costs • Higher AEP • Lower CAPEX with sharing of existing infrastructure — Substation — Switchgear — Access to road and land — Grid Connection	• Quick installation • Remote monitoring and control • Easy scalability • Lower operating costs than diesel	• Flexibility for balancing baseload generation • Cost competitive large-scale energy storage systems • More predictable than wind • Time shifting • Enhanced frequency response • Participation in Frequency Regulation Market

	Recips, SCGT or CCGT+BESS	BESS Upgrades to Existing GTs	Packaged Battery Energy Storage System
			
SOLUTIONS	Hybrid offerings for all GT/CCGT and gas engines	Upgrades to existing GTs	Residential, C&I, utility scale applications
VALUE PROPOSITION	• 30% less CAPEX vs. standalone battery • Enhanced ancillary services — Higher primary frequency response — Spinning reserve without fuel burn • Instant power to grid — Faster CC startup — Compensate for ST during startup • Higher peak plant output	• 30% less CAPEX vs. standalone battery • Enhanced ancillary services — Higher primary frequency response — Spinning reserve without fuel burn • Instant power to grid • Higher peak plant output	• Instantaneous power • Zero emissions • Participation in frequency regulation market • IQ Intelligent DC network — Future growth and optionality — Higher system resiliency — Fast charging capability without electric system upgrades • Dispatchable solar and wind • Modular, scalable platform • Edge enabled

BUILDING BLOCKS

Battery Energy Storage Solutions (BESS)

GE'S MODULAR SOLUTION: GE understands that the power and energy needs of customers are vastly different. Our energy storage solutions can be tailored to your operational needs: enabling efficient and cost-effective storage, distribution and utilization of energy where it's needed and when it's needed. Built with GE's superior design and technology, our energy storage technology delivers high performance in the most demanding applications.



CASE STUDIES

01 ***The Imperial Irrigation District's (IID) 30 MW/ 20 MWh Battery Energy Storage System (BESS)*** *began commercial operational in October of 2016. The BESS was immediately impactful in the operation of the IID grid by reducing the Balancing Area Contol Error Limits (BAAL) excursions by 83% and eliminating BAAL excursions greater than 20 MW compared to the three months before and after operation began.* ***The IID BESS provides 60 MW of bi-directional fast flexible regulation and 30 MW of spinning reserve capability*** *enabling IID operators to shut down gas fired generation operating at minimum power. This enables an optimized system dispatch which increases overall system efficiency. Additional essential grid services provided by the GE supplied BESS are solar following, Automatic Generation Control (AGC), Area Control Error (ACE) control mode, frequency response and black start functionality.* ***The IID BESS black start functionality is a first for North America*** *and provides IID critical system restoration capability. This functionality included electrifying part of the IID 92KV grid and back feeding the generator step-up providing all the auxiliary power loads required to start the 44 MW gas turbine. The gas turbine was started and synchronized to the BESS. The BESS immediately became a dynamic system load enabling the gas turbine to maintain its correct voltage and frequency as additional load was added.*

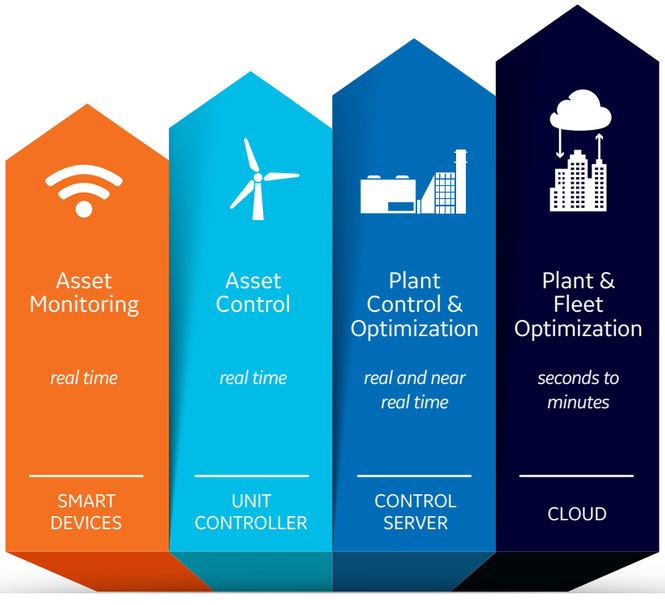
02 ***Hybrid Facility at GE's Power Electronics Factory in Berlin****. In reaction to Germany's energy transition roadmap, GE initiated a smart and fully integrated hybrid power plant consisting of a reciprocating engine, solar PV, battery storage, and a control system on the site of GE's Power Electronics factory in Berlin. The rating of the system is designed to best fit the economic benefits of the site. While still maintaining grid code compliance at all times, this hybrid solution led to a reduction in operating costs of the local factory and all of the power electronics for the system were manufactured on site.*

BUILDING BLOCKS

Industrial Internet Control System (IICS)

THE HARDWARE AND SOFTWARE THAT FORM THE IICS IN A HYBRID POWER PLANT IS SOMETIMES REFERRED TO AS THE "SECRET SAUCE" OF THE SYSTEM. IT ENABLES THE INDIVIDUAL COMPONENTS IN THE SYSTEM TO OPERATE EFFECTIVELY TOGETHER AND INTERFACE SEAMLESSLY WITH THE GRID.

GE's hybrid plant control solution is an integrated plant controller built on the IICS—a secure, scalable, and distributed control architecture with a user experience that reduces costs and increases operator efficiency. The IICS is designed to leverage the power of the Industrial Internet using GE's Predix platform that spans from the sensors at the edge to the cloud to create an ecosystem of connected local plant controls, supervisory optimization applications, and centralized business applications.



<2% power industry data currently analyzed

Digital Solutions

FLEXIBILITY
- Startup path options
- Fast load following

CAPACITY
- Boost output
- Manage trades

RELIABILITY
Enhanced grid services

AVAILABILITY
Performance recovery odometers

THE DIGITAL JOURNEY BEGINS WITH THE CREATION OF AN INTEGRATED PLANT SYSTEM MODEL THAT INCORPORATES THE 3D ARRANGEMENT WITH ITS DIGITAL TWIN,

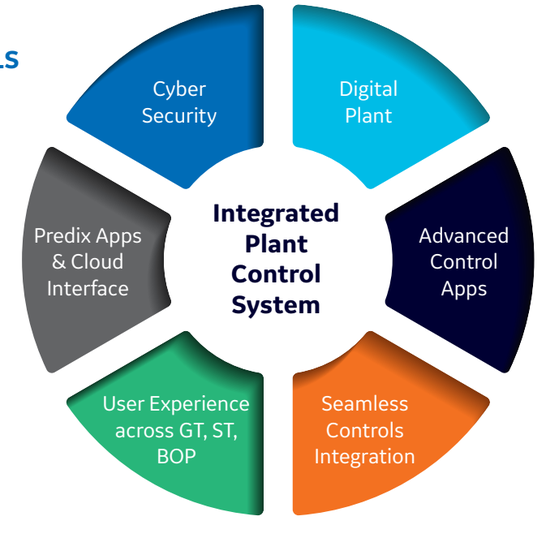
a collection of physics-based methods and advanced analytics that model the present state of assets in a virtual view of the power plant.

These system-level models utilize both physics-based domain knowledge as well as terabytes of operational and test data to simulate asset-level and plant-level performance, cost, emissions, and life. GE's machine-learning algorithms will evolve the Digital Twin throughout the plant's life cycle and build "what if" scenarios to help improve plant design, construction and operation. Once constructed, derivatives of this Digital Twin are core to the software solutions (apps) that control and optimize operational outcomes such as flexibility, capacity, efficiency, availability, and emissions.

Integration Advantage of an OEM

GE'S INTEGRATED PLANT CONTROLS SOLUTION IS MORE THAN A SUPPLY OF CONTROL SYSTEM HARDWARE AND SOFTWARE.

It includes the OEM and System Integration value-added engineering to bring consistency and harmonization of controls for a common look and feel and operating experience across the plant equipment and systems. The GE Integrated plant control solution provides benefits to the end user for operations and maintenance; benefits to the EPC for engineering time and quality; while enabling design, installation and commissioning cycle advantages.



RENEWABLE SYSTEMS

Wind Integrated Solar Energy (WiSE)

THE CHALLENGE

In a “Wind Integrated Solar Energy” solution (WiSE) owners integrate wind and solar at the wind turbine level instead of farm-level rather than running a wind and solar plant independently. Integrating at the wind turbine level leverages the existing wind converter as a hybrid converter to source AC and DC power together, eliminating the need for a separate solar inverter. With the integration at the turbine level one can also leverage the existing electrical connection infrastructure and Balance of Plant equipment which reduces the overall CAPEX per MW output. In addition, combining complementary wind production and solar production enables a more stable and higher annual energy production (AEP) while leveraging one common Operations & Maintenance provider. The GE WiSE solution comes with a Hybrid Control & SCADA architecture which manages and controls both the wind and solar energy. Source segregation with separate metering enables individual Power Purchase Agreements.

BENEFITS

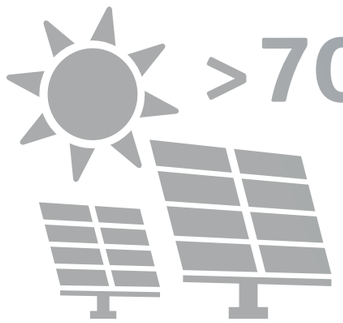
- Lower CAPEX/MWh
- Lower OPEX/MWh
- Higher and more stable AEP. By adding up to 650 kW of Solar PV panels to a 2 MW GE Wind Turbine, one can achieve an additional 8–9% AEP and 3–4% CF (Capacity Factor).
- Improved LCOE on hybrid farm
- Comprehensive service from GE for both wind and solar systems
- Increases AEP and CF without the need to increase a farm’s interconnect or evacuation limit

CASE STUDY

Red Lake Falls, Minnesota, United States
Two 2.3-116 wind turbines

1 MW solar

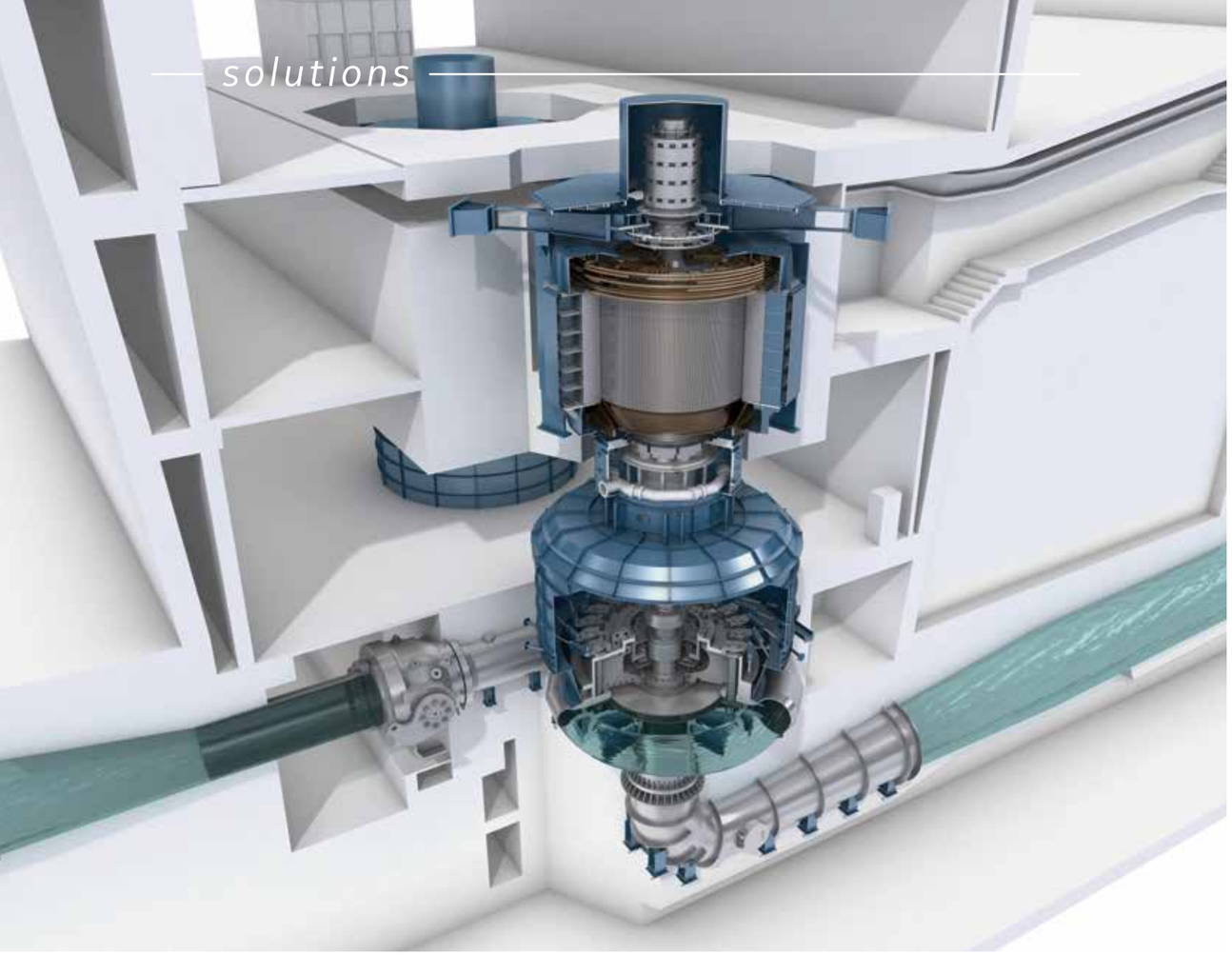
WiSE technology platform

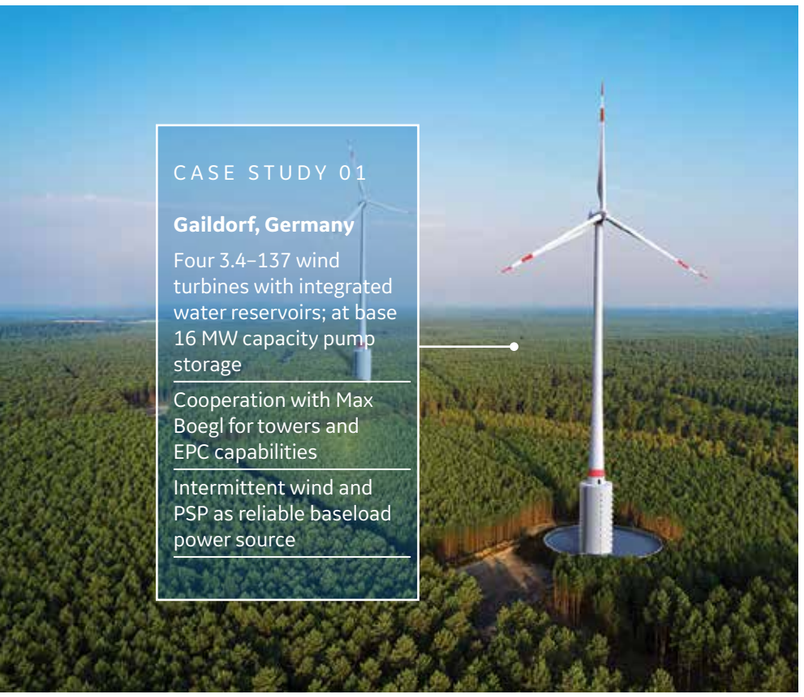


>70 GW

Solar photovoltaic installations globally in 2016

Solar and wind are more predictable together than they are on their own





CASE STUDY 01

Gaildorf, Germany

Four 3.4–137 wind turbines with integrated water reservoirs; at base 16 MW capacity pump storage

Cooperation with Max Boegl for towers and EPC capabilities

Intermittent wind and PSP as reliable baseload power source

CASE STUDY 02

Gilboa, Israel

Two GE 150 MW Pump Turbines for Pumped Storage

GE in charge of O&M for 20 years

Israel's first Pumped Storage plant; expected commissioning 2018

RENEWABLE SYSTEMS

Hydro Pumped Storage

to integrate intermittent renewable energy into the power grid

DESCRIPTION

Intermittent renewable resources including solar and wind generation are often not aligned with demand. Hydro's storage capabilities, specifically pumped storage, can help to match solar and wind generation with demand.

Pumped storage plants store energy using a system of two interconnected reservoirs with one at a higher elevation than the other. Water is pumped to the upper reservoir in times of surplus energy and, in times of excess demand, water from the upper reservoir is released, generating electricity as the water passes through reversible Francis turbines on its way to the lower reservoir. The process is then repeated with an overall cycle efficiency of 80%.

For even more flexibility, pumped storage plants can be equipped with variable speed technology which enables the plant to provide power regulation capabilities in generation and pumping modes. Traditional fixed speed pumped storage can only provide power regulation in generation mode. GE is a world leader in pumped storage plant equipment and supplies in-house capabilities not only for turbines and generators but also the full electrical balance of plant including power converters, transformers HV switchgear and circuit meters.

Pumped storage can deliver ancillary services to improve grid stability by providing grid frequency support in both directions, reactive power compensation, voltage support, black start capability and large-scale energy storage. The high inertia of rotating machines can also stabilize the grid in case of disturbances, which influences grid frequency.

BENEFITS

- PSP can provide a wide range of ancillary services needed for system operability in the future low-carbon world, with capabilities similar to or in some cases better than thermal generation and other energy storage technologies
- PSP is the most economical storage technology for long discharge periods today
- PSP enables access to incremental revenue streams through participation in local ancillary services markets

Limmern pumped storage plant (Linthal, Switzerland).

solutions

THERMAL SYSTEMS

Simple Cycle Gas Turbine + BATTERY

Hybrid Gas Turbine

DESCRIPTION

Battery storage systems can be integrated with existing or new simple cycle gas turbine power plants. Simple cycle installations focus on enhancing the peaking and grid-following attributes that are typical of today's simple cycle gas turbines. Hybrids offer reduced system operating costs, creating value for power providers and ratepayers. The upgrade enables contingency (spinning) reserve without fuel burn between demand events.

This also enables high speed regulation, primary frequency response, and voltage support with the combined response of the gas turbine and battery storage system. Finally, the solution can be used to enhance peaking megawatts (MW) with the additional capacity of the battery and provide black start capability to the site.

These hybrid solutions can be applied to aeroderivative and heavy duty gas turbines in many size ranges. Hybrid packages are fully integrated and the performance is backed by GE Power.

FEATURES

Representative values for the LM6000 Hybrid are shown below. Actual attributes are dependent on the gas turbine platform and site specific requirements.

- 10 MW Li Ion Battery
- GE Brilliance Inverters
- OpFlex* Hybrid Upgrade package
- Mark VIe Control System
- GE Proprietary Hybrid Turbine Controls

BENEFITS

Attributes without Fuel Burn

- Instant response, always ready technology
- 50 MW of operating reserve
- Primary frequency response
- -8 to +5 MVAR voltage support
- 134 MW-secs inertia with synchronous condensing
- Black start technology
- Demand charge savings

Attributes with Fuel Burn

- 50 MW peaking energy for local contingency
- 25 MW of high speed frequency regulation
- +10MW peaking power
- Self-managed BESS state of charge

GE gas turbines are integrated with packaged storage solutions and a proprietary control system. The control system manages gas turbine output, battery storage output, and system tate of charge to provide the best outcomes from the hybrid installation at all times. These systems can be customized to your site-specific needs and market conditions to maximize the solution's benefits.

Photo provided by Southern California Edison

CASE STUDY

Southern California Edison (SCE) *installed the world's first battery storage and gas turbine hybrid system. The LM6000 Hybrid EGT was installed at two sites in California in response to the state's changing regulations and grid requirements and will ultimately support increasing renewable energy capacity on the grid. The system has been operational since early 2017.*

AWARDS FROM

ENERGY STORAGE NORTH AMERICA

EEI Edison Electric INSTITUTE

"GE's new LM6000 Hybrid EGT product fits well with SCE's objective of providing cost–effective, innovative solutions that enhance grid reliability, flexibility, and fast response for our customers.

PHIL HERRINGTON
Vice President of Generation, Southern California Edison

**Trademark of the General Electric Company*

Typical configuration of a 2x6F.01 plus battery conceptual design

CASE STUDY

In a 2x6F.01 installation with a 55 MW/18 MWh battery, GE's hybrid solution can provide full combined cycle output (162 MW) within 13 minutes of engine start. A standard 2x6F.01 without battery storage would take more than twice as long to achieve full combined cycle output.

In a Primary Frequency Response application, a 9F.03 CCGT with a 9 MW/2.5 MWh battery can provide the same capabilities as an appropriately sized standalone battery solution... at a 30% lower capital cost.

THERMAL SYSTEMS

CCGT + BATTERY

Improving Combined Cycle Flexibility and Utilization with Battery Storage

DESCRIPTION

Coupling battery storage with a GE combined cycle power plant offers users the benefits of the latest advances in storage technology, while maintaining the reliability expected from a manufacturer with more than 60 years of gas turbine experience.

GE's hybrid battery storage solution can be added to existing combined cycle plants, integrated with new combined cycle plant installations during construction, or even included as a complete upgrade package to convert from simple cycle operation to combined cycle + battery storage. This modular approach enables GE to deliver the right solution to help maximize the value of your installation.

BENEFITS

There are several opportunities for a battery storage solution to add value to a combined cycle power plant:

- Faster combined cycle startup
- Simple cycle flexibility with combined cycle efficiency
- Lower CAPEX than standalone storage solutions
- Black start capability without needing a backup diesel genset
- Enhanced grid frequency regulation
- Additional peak capacity during periods of high energy demand/ high pricing

Most customers will be able to recognize multiple benefits, further enhancing the value.

The advantage of our single-OEM offering is that GE will work with you to design a solution that meets your specific needs, while ensuring that all the components work together seamlessly. With our intimate knowledge of the capabilities of the individual products, we can optimize the integration to provide the highest performance while minimizing cost.

THERMAL/RENEWABLE SYSTEMS

gas engines + RENEWABLES + battery

THE CHALLENGES

To compensate for the volatility inherent in power supplied through renewable resources, you need complementary, dispatchable power solutions. Your toughest power demands require flexible solutions that support intermittent and decentralized generation while enhancing grid stability. Finally, any solution must simultaneously help you balance environmental and economic considerations.

HOW GE CAN HELP

Combining renewable systems with GE's flexible Jenbacher* gas engine technology, innovative battery solutions, and intelligent energy management unlocks significant benefits that can help improve your energy portfolio and reduce operating costs.

Hybrid reciprocating engine systems not only provide the equivalent of a spinning reserve without any fuel burn, but can also enhance peaking megawatts with the additional battery capacity to let you capture price spikes. With fast frequency response, voltage support, and black start capability, Jenbacher gas engine hybrid solutions enable excellent renewables integration with a low CO_2 footprint. Additional advantages include fast startups in less than five minutes, capability for multiple starts per day, and low minimum power requirements.

GE's digital solutions powered by Predix enable better power generation asset integration and real-time interaction with the grid.

TYPICAL SYSTEM

- 400/490 kWel/kWth gas-fueled Jenbacher cogeneration unit
- 600 kWp solar PV
- 100 kW/200 kWh battery storage system
- 25 m^3 buffer tank (heat)
- myPlant* Asset Performance Management solution
- Energy Management System

**Trademark of the General Electric Company*

CASE STUDY

Developed in a collaboration between GE, BLS Energieplan, Kofler Energies, and BELECTRIC, the groundbreaking highly integrated hybrid power plant in Berlin, Germany, provides onsite, thermal and electrical energy from photovoltaics and gas-fueled cogeneration. The hybrid station's features include:

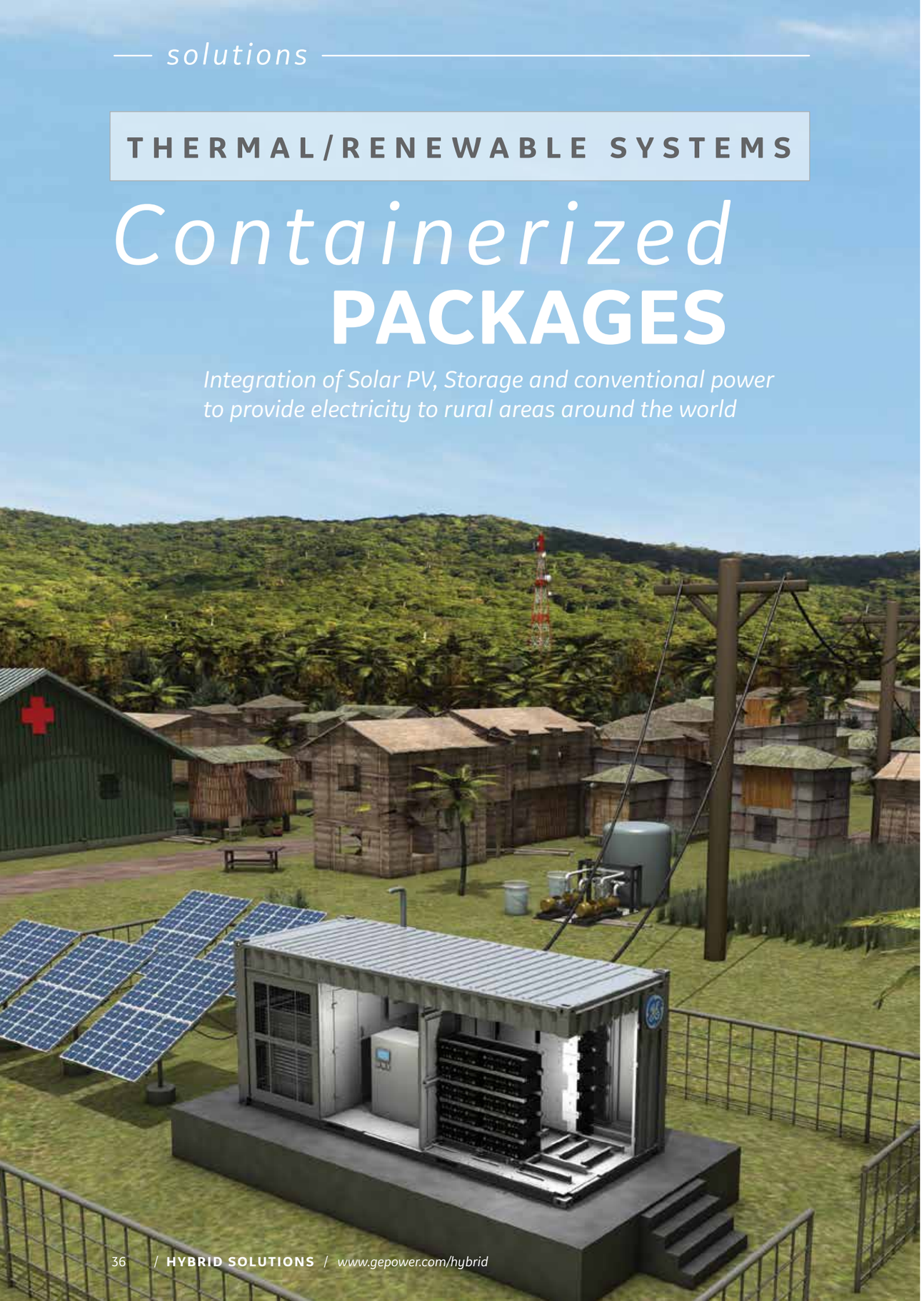
- 600 kW solar power plant
- 400/490 kWel/kWth gas-fueled Jenbacher cogeneration unit powered by one of GE's Jenbacher J312 gas engines
- Battery storage system capable of storing up to 200 kWh of excess electricity

> As a flagship project, the German hybrid power plant in the Marienfelde district of Berlin shows that Combined Heat and Power (CHP), solar power, and battery systems provide exceptional balance over the course of the year. This combination enables excellent self-sufficiency, supports a reliable power supply and offers the ability to store surplus energy—and use it efficiently, either internally or externally.
>
> **GÜNTER NICKEL**
> *CEO of Kofler Energies AG*

THERMAL/RENEWABLE SYSTEMS

Containerized PACKAGES

Integration of Solar PV, Storage and conventional power to provide electricity to rural areas around the world



THE CHALLENGE

Globally, more than 1.2 billion people, or 274 million households, do not currently have access to modern energy such as electricity and lighting. Access to affordable modern forms of energy is not only a prerequisite for economic prosperity, but also for local growth and sustainable development. According to various sources:

- More than 2 million premature global deaths occur annually as a result of indoor air pollution primarily due to fuel used for lighting and cooking
- 50% of care facilities in developing countries have no or unreliable access to electricity

TRENDS

Record deployment of intermittent renewable wind and solar PV resources

- Growing demand to replace expensive baseload diesel fuel generation with green, CO_2 friendly energy
- Exponential reductions in the cost of batteries for storage
- Digital solutions that enable better integration of generation assets and real-time interaction with the grid
- Environmental goals that are being implemented by a wider range of countries, cities, communities, and businesses

HOW GE CAN HELP

GE's packaged solution, which includes solar, batteries, a reciprocating engine, and power electronics, will generate sustainable and reliable power for off-grid applications, including village electrification, or powering remote commercial and industrial applications. It also includes a connection to Predix, the industrial internet platform, to remotely monitor and control the system, which enables:

- Remote monitoring and diagnostics that enable proactively identifying issues using GE's Digital Twin technology
- Operational planning through a variety of analytics, including supply and demand forecasts
- Connection with diverse metering technology, enabling remote connect/disconnect and demand response
- Flexible revenue models through supporting multiple tariff schedules and integration with mobile payment systems

BENEFITS

- Cost competitive renewable hybrid technology **lowers traditional diesel operating costs by up to 40%**
- Easy deployment with containerized and pre-configured solution
- Allows retrofitting existing diesel assets to reduce fuel consumption
- Turnkey installation services reduce deployment time and cost

CASE STUDY

Tayabpur, in Bihar, India

15 kW microgrid with solar, batteries, and a diesel engine

Providing 24/7 power to a remote village

All production data transmitted in real-time to Predix for analysis

enablers

hy·brid car

/'hī brid kär/

Noun
A car that uses one or more means of propulsion, typically an internal combustion engine and an electric motor. They use less fuel and emit less CO_2 than most conventional non-hybrid vehicles.

GE Store

The GE Store is the global exchange of technology, talent, and expertise across GE's diverse businesses and markets. GE businesses give and take from the store.

DRIVING COMPETITIVE ADVANTAGE ACROSS OUR BUSINESSES

We drive enterprise advantages that benefit our customers through what we call the "GE Store." It means that every business in GE can share and access the same technology, markets, structure and intellect. The value of the GE Store is captured by faster growth—it makes the totality of GE more competitive than the parts. No other company has the ability to transfer intellect and technology as we can through the GE Store.

> *GE Global Research is at the heart of the GE Store. It's our role to identify, invent and develop technologies that create better GE businesses and ultimately redefine the technical benchmarks of our industries. I call it Technology+...the powerful combination of technical expertise and strategic business thinking.*

VIC ABATE
Senior Vice President & Chief Technology Officer
GE Global Research

GE Energy Financial Services

/ www.geenergyfinancialservices.com /

A STRATEGIC GE CAPITAL BUSINESS, GE ENERGY FINANCIAL SERVICES IS A GLOBAL ENERGY INVESTOR THAT PROVIDES FINANCIAL SOLUTIONS THAT HELP MEET THE WORLD'S ENERGY NEEDS.

Drawing on its technical know-how, financial strength and strong risk management, GE Energy Financial Services invests in long-lived and capital intensive projects and companies. The firm has 35+ years of experience managing energy assets through multiple economic cycles, and a global portfolio that spans conventional and renewable power, and oil and gas infrastructure projects.

GE Energy Financial Services is part of the GE Store and is able to provide unique customer value by leveraging GE's industrial energy heritage and strong technology footprint to offer access to capital and expertise.

As a part of GE, we enjoy great financial strength, but our value to clients extends far beyond. We are a small company of 300 people, with deep industry expertise, within a large company of 300,000.

AT-A-GLANCE

With the strength of GE's balance sheet, we:

- Hold approximately $13 billion in global energy assets (~70% equity, ~30% debt); 220 investments
- Serve approximately 300 customers: energy project developers, independent power producers, energy technology companies as well as pipeline companies
- Diversify across renewable energy, thermal power and midstream oil and gas
- Committed more than $15 billion in cumulative global renewable energy investments, primarily in wind and solar
- Invest equity and debt in power projects that we or third parties operate. Together, these projects have a capacity to produce ~45 gigawatts of power
- Invested in projects with a cumulative 47,000 miles of natural gas pipelines in North America
- Offered ~$1.2 billion in debt finance in 2016

PRODUCTS

- Structured and common equity
- Leveraged leases
- Asset-backed revolvers
- Senior secured debt

CAPABILITIES

- Develop financing solutions for hybrid applications, leveraging GE's legacy energy structuring expertise in renewables, thermal and oil and gas
- Leverage global originations and capital markets capabilities to lead, arrange and syndicate transactions, providing tax equity, project and debt financing

SOLUTIONS

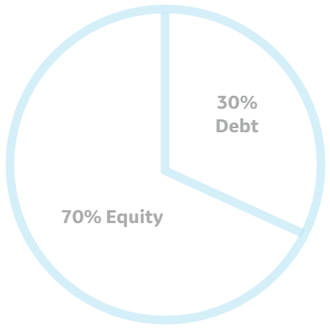
- Project finance
- Corporate finance
- Acquisition finance
- Commercial debt and leases
- Senior loan arranging and syndication
- Monetizations
- Global capital markets access

INVESTMENTS IN

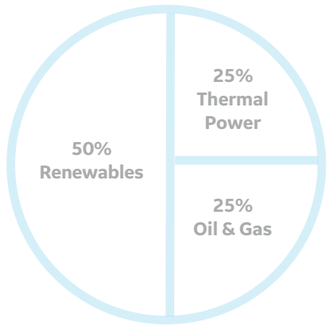
- Renewable energy
- Thermal power
- Oil and gas infrastructure

LOCATIONS

Our hub offices are located in Stamford, New York, Houston and London, with 16 regional locations globally.



Range of financial solutions



Across energy markets and essential infrastructure

Energy finance is what we do;

it's all we do.

~$15B
in cumulative global renewable energy commitments

45GW
power portfolio

>$6B
invested in oil and gas infrastructure

GE Energy Consulting

/ www.geenergyconsulting.com /

FOR NEARLY A CENTURY, A CORE GROUP OF LEADING GE TECHNICAL AND BUSINESS EXPERTS HAVE FOCUSED THEIR ENERGIES ON SOLVING THE ELECTRIC POWER INDUSTRY'S MOST PRESSING CHALLENGES—DRIVING THE EVOLUTION OF ELECTRIC POWER SYSTEMS WITH GREATER AFFORDABILITY, RELIABILITY, AND EFFICIENCY BY PROVIDING TECHNO-ECONOMIC SOLUTIONS.

Today, GE's Energy Consulting team continues this tradition by providing innovative solutions across the entire spectrum of power generation, delivery, and utilization. With our cross-company resources, GE's Energy Consulting business is able to serve a diverse global client base with a strong local presence.

SYSTEMS ENGINEERS SOLVING CHALLENGES THAT DELIVER CUSTOMER VALUE

Services:	POWER ECONOMICS • Power systems strategy • Energy financial analytics	POWER SYSTEMS OPERATIONS & PLANNING • Transmission and distribution studies • Equipment applications	GLOBAL POWER PROJECTS • Thermal • Renewables, controls and protection
Value Outcome:	PROFITABLE and SUSTAINABLE investment strategy	COMPLIANT and RELIABLE from concept to engineered design	PROJECT LIFE-CYCLE testing and compliance

PSEC PROGRAM OVERVIEW

The Power System and Energy Course (PSEC) is GE's highly regarded energy education program. With a 67-year history and over 1,800 graduates worldwide, PSEC is designed to enhance the skills and knowledge considered essential for power system engineers and other energy professionals. PSEC courses provide valuable insights about industry trends, best practices, and the latest technologies.

The professional experts at GE Energy Consulting are considered to be among the best practical engineers in the world, understanding customer problems, having proven real-world expertise in a wide range of technologies—from power systems planning and energy economics to power markets and emerging generation solutions—including renewables, storage and hybrid systems. This program enhances learning through the use of the latest industry software and includes tours of GE's research centers, manufacturing facilities, and other industry businesses.

SOFTWARE PRODUCTS

Focused on the planning, design, and operation of interconnected power systems.

MAPS*
- Evaluates power system economics and impact of congestion
- Provides locational prices, unit schedules, line flows, emissions
- Used in high wind penetration and standard market design studies
- Supports GE's multi-billion dollar energy investment portfolio

PSLF*
- Simulates physical behavior of the grid and connected equipment
- Provides voltages and line flows, system dynamic behavior
- Extensively used to study 2003 Northeast US blackout
- Mechanism for ensuring that equipment is properly modeled

MARS*
- Assesses reliability of supply in meeting energy demand
- Provides of load expectation (LOLE) and other reliability indices
- Applied for regional reliability and reserve margin studies
- In use at most ISO's in the US

**Trademark of the General Electric Company.*

GE Ventures

/ www.geventures.com /

A CATALYST TO GE'S GOAL OF MAKING THE WORLD WORK BETTER, AND AN INNOVATION ENGINE WITHIN GE.

GE Ventures finds the best ideas that emerge from the latest research, invests in promising start-ups, commercializes GE's IP, and creates its own businesses. The GE Ventures team includes investors, licensees, entrepreneurs and industry experts.

$200M
invested per year

$3–5M
investment sweet spot

90+
companies in our investment portfolio

AT A GLANCE

- Invest up to $200 million per year as equity in early stage private companies from seed to growth
- Over 90 companies in the investment portfolio
- Venture investment sweet spot: $3–5 million with opportunities for follow-ons as companies grow
- Actively license GE IP to partners who can use it in innovative ways to accelerate their own technology development and create differentiated offerings

HOW WE WORK

- **Investing:** We invest and partner with startups to accelerate growth and commercialize innovative ideas in strategic areas for GE.
- **New Business Creation:** We create and build new businesses that develop innovative solutions and business models.
- **Licensing and IP Development:** We provide our partners with access to GE's vast technologies for them to use in innovative ways, helping them accelerate their own technology development and differentiating them in the marketplace.
- **Industry & Community Transformation:** We help foster innovation for major health challenges
- **New Market Development:** We partner with leading external luminaries to define and drive the next wave of scientific and technical breakthroughs

SERVING GE'S CUSTOMERS

Operating at the cutting edge of innovation and new business formation, GE Ventures brings the future of industries to our customers when they need it most—right away. We build bridges between the disruptive companies operating at the edge of innovation and the existing ecosystems where GE's domain expertise and physical equipment play a major role. As digital integrates deeper into industrial, our portfolio of 90+ companies across the globe is helping blaze the trail and accelerate the transition.

LOCATIONS

GE Ventures Headquarters are in Silicon Valley with offices in Boston, Niskayuna, Washington, D.C., Chicago, Houston, Shanghai, and Israel.

Ecomagination

/ www.ge.com/about-us/ecomagination /

Ecomagination is GE's business strategy to deliver improved economic and environmental outcomes for our customers and in our own operations. As GE continues to evolve, so does Ecomagination. We are demonstrating how a Digital Industrial company uses innovative and intelligent resource-efficiency solutions to help our customers grow and compete.

Ecomagination drives global impact by delivering cleaner and more efficient technology solutions, partnerships and new business models—as well as convening key stakeholders to take action. The deployment of these solutions at global scale drives significant outcomes for our customers and their communities across sectors as diverse as the Power Generation, Transmission & Distribution, Water, Transportation and Healthcare industries.

GE Ecomagination is applying new digital industrial solutions to the world's most pressing energy and water challenges. But we can't do it alone.

GE is partnering with six global, like-minded companies to co-create and commercialize transformative solutions to these challenges.

With ground-breaking technology, new business models and innovative funding structures, we will lead a new era of industry and establish a network of problem solvers.

With our collective scale and reach we will have significant business and environmental impact and inspire others to take action.

bhpbilliton

intel

MWH

Statoil

TOTAL

Walmart

$20B GE investment to date in Ecomagination research and development

74 Ecomagination qualified solutions

18% reduction in GE's GHG emissions from the 2011 baseline

29% reduction in GE's water use from the 2011 baseline

"Our goal is to create a network effect. We want to inspire more companies to work together and tackle the world's greatest resource problems. This is about co-development of solutions that can be scaled globally. Global water and energy challenges require immediate action and the business community isn't going to wait.

DEB FRODL
Global Executive Director Ecomagination

GE Beliefs

Helping us work together to change our culture and deliver on simplification

We are being challenged to think, act and lead in new ways, pushing our boundaries to create a GE that is faster, simpler and more customer-focused.

To accelerate our journey we must embrace a new way of working that enables us to: keep pace with change, harness complexity, transform our culture and deliver results.

1. **Customers Determine Our Success**
2. **Stay Lean to Go Fast**
3. **Learn and Adapt to Win**
4. **Empower and Inspire Each Other**
5. **Deliver Results in an Uncertain World**

"Let's be amazing for our customers. Let's be the best team players in the world.

JOHN FLANNERY
CEO of GE

GE's Commitment

Delivering solutions to help our customers successfully navigate the energy ecosystem transformation

GE has been at the forefront of the electricity industry since its earliest days—inventing, designing, and deploying the technologies that improve the quality of life for billions of people.

Thomas Edison, GE's founder, built the first commercial central power plant and associated distribution network at Pearl Street in New York City in 1882. Since that time, the industry has evolved and advanced as new fuels, materials and systems have been used to create and distribute electricity. Every step of the way, GE has contributed its expertise and experience to bring electricity safely and cost effectively to the world.

We firmly believe that customers determine our success—and we provide technology, solutions and services across the entire electricity value chain from the point of generation to consumption. We are transforming the electricity value chain by uniting all the resources and scale of the world's first Digital Industrial company.

Today, GE's customers operate in more than 150 countries and our equipment is responsible for providing approximately one-third of the world's electricity.

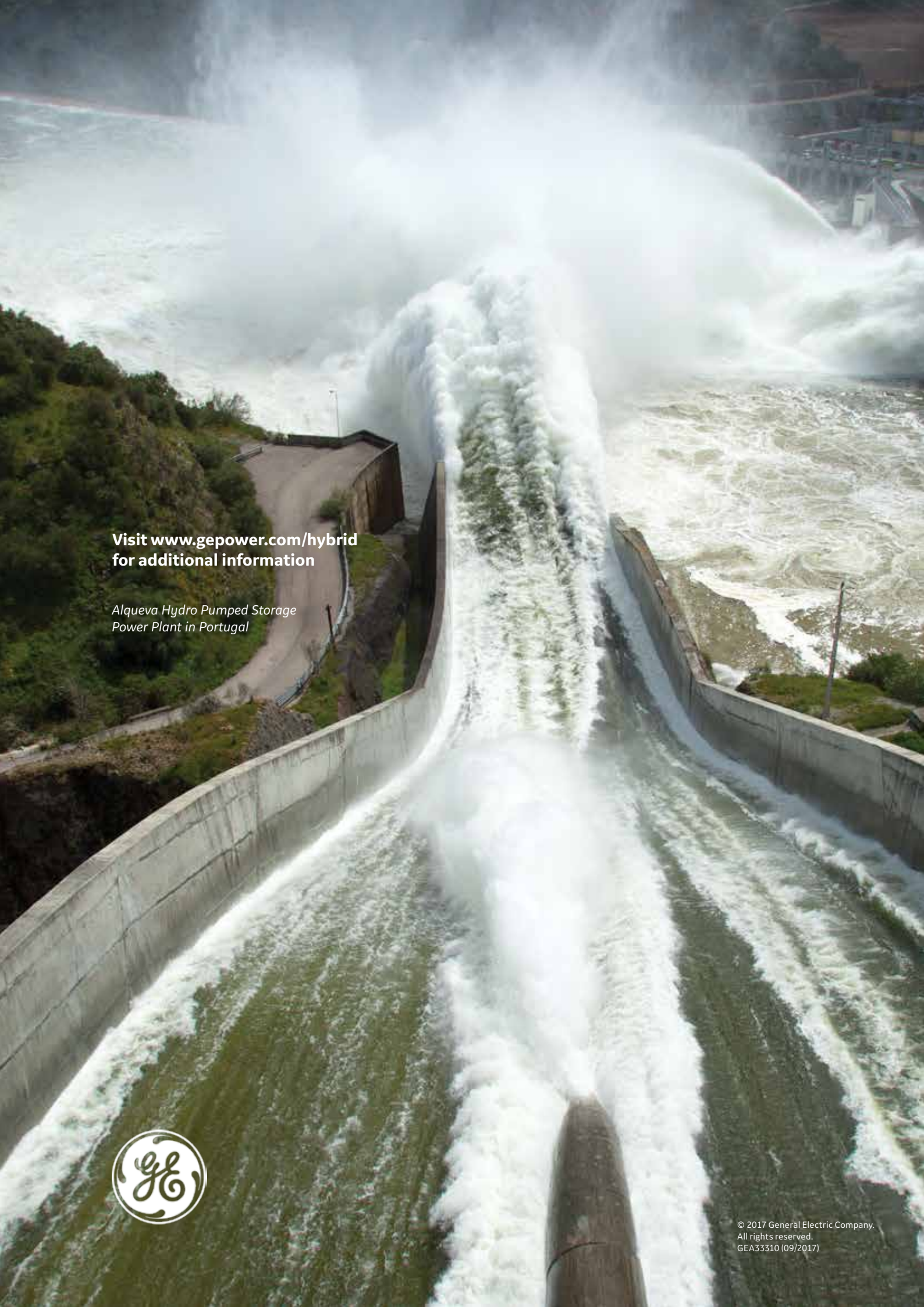
As impressive as these statistics are, we will not be satisfied until everyone on the planet has access to affordable, reliable and sustainable electricity.

The energy industry is undergoing massive transformation on a scale and at a pace never experienced before. These transformations are occurring to a varying degree in each part of the world, but one thing is certain, the global electricity industry will look markedly different in the future. GE believes hybrid power plant solutions that combine the best attributes of different technologies will be an integral part of the future energy mix. We are committed to providing our customers the best solutions to help them be successful in this future energy ecosystem.

Russell Stokes
President & CEO
GE Power

Jérôme Pécresse
President & CEO
GE Renewable Energy

Visit **www.gepower.com/hybrid** to help design a hybrid system for your unique needs.



Visit www.gepower.com/hybrid for additional information

Alqueva Hydro Pumped Storage Power Plant in Portugal

GEA33310 (09/2017)