Energy Creation Technologies: Current Status and Future Outlook

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1. Introduction

In the "energy creation" sector, Fuji Electric has worked to increase the efficiency and performance of thermal power generating facilities, has made deliveries of such to many countries throughout the world in addition to Japan, and has contributed to the stable supply of energy in the world. Moreover, in the renewable energy sector that includes geothermal power generation and the like, Fuji Electric has also worked to develop power generating facilities that are capable of supplying stable energy. Further, with an eye toward renewable energy, Fuji Electric is also advancing the technical development and commercialization of photovoltaic power generation, wind power generation, biomass power generation, and the like. This paper describes the present status and future outlook for energy creation technology that will contribute to a more stable supply of energy and a reduced impact on the environment.

2. Global Energy Situation

2.1 Global energy trends

The global demand for energy is expected to grow significantly due to the economic growth of emerging countries and an increase in population. "World Energy Outlook 2012,"(1) a 2012 report by the International Energy Agency (IEA), predicts that demand for electric energy will increase greatly, growing at an annual rate of 2.2%, and that by 2035, the global demand for electric energy will be 36,637 TWh (see Fig. 1). The report predicts an annual growth rate of 0.9% for developed countries, and an annual growth rate of 3.3% for emerging countries.

Thermal power generation mainly from coal-fired power generation and natural gas accounts for a large proportion of energy production, while the percentage of thermal power from oil-fired power generation is decreasing. Meanwhile, reducing the environmental impact is also a major issue, and energy-friendly renewable energy that does not emit CO_2 has increased significantly, with particularly large increases in biomass power generation, wind power generation and photovoltaic power generation. The percentage of power generation from renewable energy, including hydroelectric power generation, will increase approximately 30%. In light of the anticipated increase in energy demand, the pursuit of economic efficiency of the power generating cost, including fuel costs, as well as the reduction of the environmental impact are important issues. With regard to coal-fired power generation, combined-cycle power generation that uses natural gas and shale gas as fuel is being introduced, and the efficiency of coal-fired power generation is being increased.

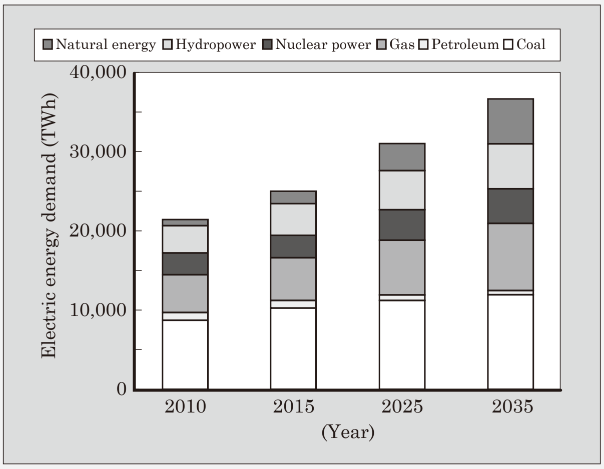

Fig.1 Global demand for electric energy

To meet the growing demand for electric energy, the capacity of power generating facilities must be increased. Figure 2 shows the global capacity of power generating facilities. The global power generating capacity in 2012 was 5,400 GW, but it is estimated that 9,300 GW of power generating capacity will be needed by 2035. However, due to such factors as aging, the need to reduce CO_2 emissions, rising fuel prices and so on, the power generating facilities currently in operation will need to be replaced with state-of-the-art power generating

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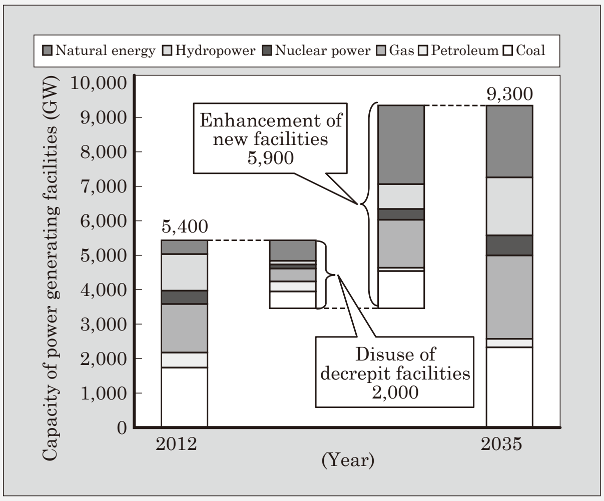

Fig.2 Global capacity of power generating facilities

facilities. The IEA report predicts that by 2035, 2,000 GW, corresponding to approximately one-third of the existing power generating facility capacity, will have been renewed, and that 5,900 GW of new power generating facilities will be built.

2.2 Energy trends in Japan

Figure 3 shows the composition of power generation capacity in Japan. As a repercussion of the tsunami-related disaster at the Fukushima Daiichi Nuclear Power Plant as a result of the Great East Japan Earthquake of March 2011, the shutting down of nuclear power plants in Japan has continued, and measures for the stable supply of electric power are being reviewed. The issue of restarting the nuclear power plants continues to be debated at a national level. The September 2012 "Innovative Energy and Environmental Strategy" indicated a policy of promoting the advanced use of thermal power generation, advanced use of heat such as through cogeneration, and the development and use of next-generation energy related technologies in order to ensure a stable supply of energy. In particular, the main features of this strategy are to enhance and augment thermal power plants and to promote the introduction of renewable energy. In the enhancement and augmentation of thermal power plants, the introduction of high-efficiency combined cycle power generation that uses natural gas as fuel and ultra super critical (USC) power generation*[1] that uses coal as fuel, and the like, have attracted attention. In terms of renewable energy, with the goal of introducing of 300 TWh (more than 3 times the current amount) by 2030, the introduction of renewable energy coupled with the "Feed-in Tariff Scheme for renewable energy" that began in July 2012 has gained momentum.

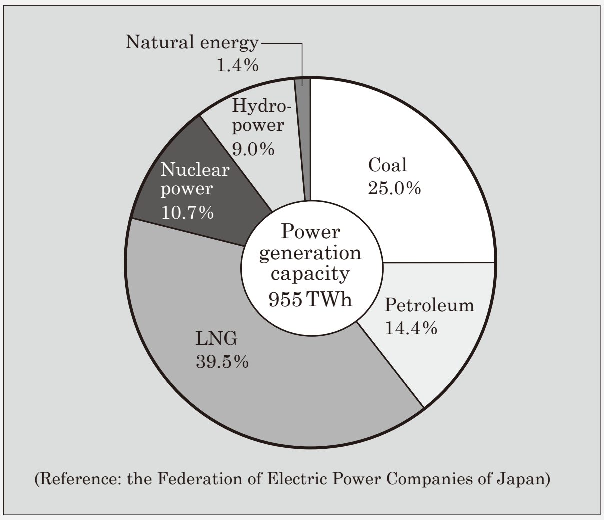

Fig.3 Composition of power generation capacity in Japan

3. Thermal Power Generation

As shown in Fig. 1, thermal power generation presently accounts for approximately 67% of the power generated to meet the global demand for electric energy, but as a result of initiatives to promote the introduction of renewable energy and so on, this percentage will decrease to 57% by 2035. Meanwhile, the demand for power can be seen to be increasing to approximately 1.5 times the present level. Under these circumstances, from the perspective of reducing CO_2 emissions and of increasing economic efficiency, including consideration of the fuel cost, oil-fired power generation will be cut in half, combined cycle power generation that uses natural gas as fuel will be increased to 1.8 times its present level, and coal-fired power generation will also be increased to nearly 1.4 times its present level mainly in emerging countries.

In the thermal power sector, high-efficiency combined cycle power generation based on a combination of gas turbines and steam turbines and that uses natural gas as fuel and ultra super critical (USC) power generation that uses coal as fuel will become the mainstream types of power generation in the future.

3.1 Combined cycle power generation

Combined cycle power generation has the characteristics of being highly efficient, contributing to the prevention of global warming with low CO_2

***1: Ultra super critical (USC) power generation**

USC power generation is thermal power generation technology in which the steam is used under the conditions of ultra super critical pressure (steam temperature of at least 593°C and steam pressure of at least 24.1 MPa). USC power generation enables the thermal energy required to vaporize water to be reduced so that power can be generated more efficiently.

Fig.4 Yoshinoura Thermal Power Station of the Okinawa Electric Power Company, Incorporated (Photo: provided by the Okinawa Electric Power Company, Incorporated)

emissions, short startup time, good tracking performance according to load fluctuations, etc., and will play an important role in future thermal power generation. Furthermore, combined cycle power generation has until now used natural gas as fuel, but recently, shale gas development has been advancing rapidly mainly in the US and expectations for the future use of shale gas with gas turbines is increasing.

Fuji Electric has also been working with combined cycle power generation, and has moved forward with the construction of combined cycle power generation equipment (two 251 MW units) at the Yoshinoura Thermal Power Station of the Okinawa Electric Power Company, Incorporated (see Fig. 4). In November 2012, Unit No. 1 completed its comprehensive testing and began commercial operation. In addition, Unit No. 2 began commercial operation in May 2013. This power generating facility was developed jointly with Siemens AG and is a single-shaft type combined cycle power generating plant that combines a Siemens-made gas turbine (STG6-4000F, F-class), a single-cylinder reheat steam turbines with axial-flow exhaust developed by Fuji Electric, and a generator. In plant performance testing, efficiency of at least 51% (HHV*2 basis) was achieved, and good results that surpassed the expectations of the original design were confirmed for the short-term load response capability and frequency adjustment capability.

In the future, combined cycle power generation will progress toward larger sizes and improved thermal efficiency as a result of higher combustion temperatures of the gas turbine. Siemens AG has also developed a larger capacity H-class gas turbine that employs a higher combustion temperature, and in an actual combined cycle power plant, that achieves the world's highest efficiency, significantly above 60% (LHV*2 basis, sending end). Fuji Electric continues to improve the performance of steam turbines and generators and to make equipment more compact, and is working on combined cycle power generation both in Japan and overseas. (see "Global VPI Insulated Indirectly Hydrogen-Cooled Turbine Generator for Single-Shaft Type Combined Cycle Power Generation Facilities" on page 113.)

3.2 Coal-fired power generation

Coal-fired power generation is being developed mainly by emerging countries in order to increase its economic efficiency. In developed countries, efforts to reduce CO_2 emissions are seen to restrict new development, but with new technical developments such as higher efficiencies resulting from the development of the ultra supercritical pressure turbine and the gasification of coal, the merit of coal-fired power generation has been reconsidered.

In the medium capacity sector, Fuji Electric has delivered many high-performance, highly reliable coal-fired power generation facilities to countries throughout the world. Recently, Fuji Electric has been working on steam turbines and generators (4 units, 300 MW) for the Haiphong Thermal Power Plant in Vietnam, and steam turbines and generators (2 units, 300 MW) for the Nghi Son Thermal Power Plant.

For ultra supercritical power generation, Fuji Electric, in collaboration with Siemens AG, has delivered the turbine and generator (1 unit, 600 MW) for Unit 1 of J-Power's Isogo Thermal Power Plant. Utilizing a main steam temperature of 600 °C and a reheat steam temperature of 610 °C, an advanced blade stage design achieves high plant efficiency and contributes to reduced CO_2 emissions and improved economic efficiency. Higher efficiency by increasing the temperature and pressure of the main steam in steam turbines will continue to be sought in the future. On the other hand, improving the reliability of turbines is also an important factor. Thus, in addition to improving the performance of the steam turbine stage, Fuji Electric continues to develop rotor material, casing material and turbine blade material, improve the corrosion resistance of turbine blades, and develop corrosion monitoring technology.

The development of 700 °C class steam temperature, advanced ultra-supercritical (A-USC) power generation technology that aims to further

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***2: HHV, LHV**

After a unit quantity of fuel placed in a constant state is completely combusted adiabatically, the amount of heat that must be dissipated in order for the combustion gas to be returned to its original temperature is called the "calorific value." The calorific value is specified as either the higher heating value (HHV), which includes the latent heat of the water vapor, or as the lower heating value (LHV), which does not include that latent heat.

improve efficiency is being advanced for next-generation steam turbines. Fuji Electric is also is advancing the technical development of A-USC technology through its participation in the "METI-sponsored development of advanced ultra-supercritical power generation." (see "Latest Steam Turbine Technologies for Thermal Power Plants" on page 107.)

4. Geothermal Power Generation

Among renewable energy sources, geothermal power has the characteristics of (a) being usable as a base load supply with an output that does not fluctuate due to weather or the like, (b) having a high capacity utilization rate, and (c) being highly economic efficiency, and is being developed in geothermal resource-rich countries throughout the world.

Geothermal resources exist in abundance in the Pacific Rim (Japan, United States, Indonesia, Philippines, New Zealand and Chile) and in Africa (Kenya and Ethiopia), and geothermal power generation is being developed in various countries. Japan is said to be ranked third in geothermal resources (having geothermal resources of approximately 23.5 GW) behind the United States and Indonesia. Fuji Electric has focused on geothermal power generation, and having been involved in the research and development of geothermal power generation equipment since the 1960s, has a successful record of delivering many highly reliable geothermal power generation systems and has a large share of the global market in terms of deliveries.

Described below are two methods of geothermal power generation, large-scale flash power generation used directly with a geothermal turbine whereby hot water and steam ejected from the ground are boiled at low pressure and only the steam is removed, and small-capacity binary power generation in which a secondary medium having a low boiling point is vaporized by relatively low-temperature geothermal water and that vapor is harnessed to rotate the turbine and generate power.

In regard to flash power generation, in October 2010, Fuji Electric delivered a 140 MW geothermal power system, the world's largest capacity for triple-flash power generation*3, to the Nga Awa Purua Geothermal Power Station in New Zealand (see Fig. 5). More recently, in December 2012, Fuji Electric delivered a geothermal power system (2 units, 55 MW) to the Ulubelu Geothermal Power Station in Indonesia. (see "Power Plant Technologies for Thermal and Geothermal Power Plants" on page 91.)

Fig.5 Nga Awa Purua Geothermal Power Station in New Zealand

In geothermal power generation, large quantities of corrosive gas and impurities are contained in the geothermal fluid and may cause such problems as corrosion, erosion-corrosion*4, scaling, and the like. Based on onsite verification test data and on inspection and maintenance data obtained from a track record of many deliveries, Fuji Electric is researching and developing optimal materials and coating technology for the turbine blades and casing in order to improve the reliability of the turbine, generator and ancillary equipment. It is important to improve both reliability and performance, and turbine blades and the like that are highly resistant to corrosion and that are highly efficient are under development. (see "Recent Technology for Improving Corrosion-Resistance and Performance of Geothermal Turbines" on page 96.)

The method of binary power generation was developed in order to effectively utilize geothermal hot water that is at a relatively low temperature, and this method is expected be introduced in small-size geothermal power systems. On the other hand, the binary power generation method can also be used with reinjection hot water that, through use of the flash power generation method, has been returned to a reinjection well because that reinjection hot water still contains thermal energy. Fuji Electric calls this power generation method "hybrid

***3: Triple-flash power generation**

In the flash method of power generation, geothermal resources extracted as hot water are separated into steam and hot water, and the separated steam is sent to a turbine, where power is generated. The separating of the steam and hot water in 3 stages is called triple-flash power generation, and enables the extracted geothermal resources to be utilized maximally.

***4: Erosion-corrosion**

Erosion-corrosion is the phenomenon whereby the thinning of metal is accelerated as a result of the synergistic action of erosion (mechanical wear due to flow and solid particles) and corrosion (electrochemical wear within a corrosive solution).

geothermal power generation" and seeks to apply it to improve the energy recovery efficiency of entire power plants. Silica scaling occurs easily in low temperature reinjection hot water, and constriction in the reinjection well must be prevented. Fuji Electric is also researching the occurrence of silica scaling in reinjection hot water, and is utilizing the results of that research to promote hybrid geothermal power generation. (see "Technology to Counter Silica Scaling in Binary Power-Generating System Using Geothermal Hot Water" on page 101.)

5. Renewable Energy

The prevention of global warming is important as a corporate social mission, and the introduction of renewable energy that does not emit CO_2 is being promoted in various countries throughout the world. According to the IEA report, the introduction of renewable energy is expected to grow at an annual rate of 6 to 8%. In Japan, the best mix of energy, distributed energy systems, the construction of smart communities, and the like are being debated as part of the national energy policy, and renewable energy is positioned as a significant portion of that policy. The Feed-in Tariff Scheme for renewable energy applies to photovoltaic energy, wind power, geothermal energy, medium and small hydropower, and biomass power generation, and stipulates that generated power is to be purchased for a predetermined term at a fixed price. For this reason, renewable energy power producers are easily able to establish business plans, and the introduction of renewable energy generation is gaining momentum. Presently, the introduction of photovoltaic power generation, for which construction is relatively simple, is advancing, but the introduction of wind power and thermal power is expected to advance subsequently. Fuji Electric is also advancing the research and development of renewable energy power generating devices and equipment, and has been working on the commercialization of high efficiency, high performance devices and plant construction with EPC*[5].

5.1 Photovoltaic power generation

Photovoltaic power generation can be broadly classified as small photovoltaic power generation systems installed on house roofs and large-scale photovoltaic power generation (mega-solar) systems installed mainly on the ground. Fuji Electric is working primarily on mega-solar. The key to photovoltaic power generating systems lies in the extent to which its economic efficiency can be increased. Important factors include minimizing loss of the power generating system, increasing the amount of power generated per unit area, improving device reliability to increase the utilization rate and thereby boost the amount of power generated annually, reducing the construction costs for photovoltaic panel installation and wiring, and so on.

Fuji Electric is applying its power electronics technology and system design technology acquired thus far to build photovoltaic power generation systems that have high economic efficiency. In the power electronics technology sector, Fuji Electric has developed a 1,000 V DC, 1 MW power conditioner (PCS) (see Fig. 6) that incorporates industry-leading advanced T-type neutral-point-clamped (AT-NPC) 3-level conversion circuit*[6] for use in mega-photovoltaic systems. The application of an AT-NPC 3-level conversion circuit dramatically reduced the switching loss and filtering loss and resulted in achieving the world's highest efficiency of 98.5%. With the DC input set to 1,000 V, DC-side loss is reduced, and lower construction costs are anticipated as a result of an outdoor type model that eliminates the need for a structure to house

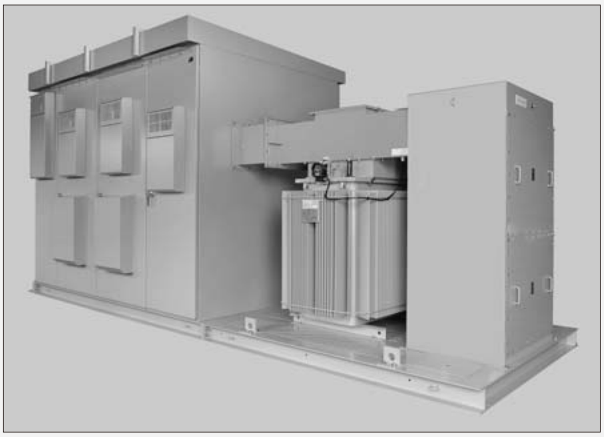

Fig.6 Outdoor PCS (1,000 V DC, 1 MW)

***5: EPC**

EPC is an acronym for engineering, procurement and construction, and indicates the engineering design, procurement of materials, and construction work as the scope of services at the time of plant construction. The contracting of this work collectively is called the EPC method or EPC business of contracting.

***6: AT-NPC 3-level conversion circuit**

Compared to a typical 2-level conversion circuit that has two output voltage stages, a 3-level conversion circuit has one additional stage. As a result, the waveform of the output line-to-line voltage more closely resembles a sine wave, and this has the advantages of allowing the LC filter of the device to be made smaller, increasing the power conversion efficiency, and so on. A conventional 3-level circuit is connected to the neutral point of a DC power supply and is therefore referred to as a neutral-point-clamped (NPC) scheme. With the advanced T-type NPC (AT-NPC) scheme, elements having different rated voltages are combined and a reverse blocking IGBT (RB-IGBT) is used as an intermediate element to simplify the circuit compared to the conventional scheme and to realize higher power conversion efficiency.

the PCS. In the system design sector, Fuji Electric is improving design techniques for a comprehensive system design that considers the installation environment and economic efficiency through optimizing the photovoltaic module and array according to the environment, reducing wiring loss, planning of interconnection equipment that conforms to the grid interconnection requirements, and designing monitoring controls that incorporate smart technology and/or are cloud based, etc. (see "Technology for Large-Scale Photovoltaic Power Generation Systems" on page 118.)

In addition, Fuji Electric plans to build a 2 MW photovoltaic power facility on vacant land in Yamanashi Prefecture in Japan. This facility will be used to carry out verification testing of the developed PCS and grid interconnection equipment, to collect data for reliability confirmation and product improvement, and to improve construction techniques. This facility is expected to be completed in March 2013, and the verification data and effective construction techniques obtained here will be applied to advance the construction of high performance and highly economic efficient photovoltaic power systems.

5.2 Wind power generation

Wind power generation occupies an important position among types of renewable energy. In Japan, onshore installations of wind power generation have been mostly small-scale until now. From the perspective of economic efficiency and due to limited installation sites, offshore wind power generation is being eyed for large-scale wind power generation (wind farms) in the future. The large-scale wind power generating equipment at such sites will have power generating capacities of 3 to 5 MW per unit. Fuji Electric is focusing its efforts on large-scale generators for wind power facilities, PCSs, power stabilization devices, and the like.

For wind power generation, it had been common to use a double-fed system that employs a speed-increasing gear to increase the rotational speed of the wind turbine and cause the generator to rotate at high speed. However, as the power generating capacity increases, such as in the case of offshore wind power, a large-size speed increasing gear becomes necessary, and trouble and maintenance associated with that speed-increasing gear becomes a large issue. As a recent trend, a direct-drive system that omits the speed-increasing gear is being used in large-scale wind power generation.

Fuji Electric has developed and commercialized a 3,000 kW permanent magnet synchronous generator for use in a direct-drive system. With the direct-drive system, the rotational speed is slow, at approximately 15 min^{-1}, and the generator is large in size, but by using a method of excitation with a permanent magnet and optimizing the ventilation and cooling system, the winding method and the structure, smaller size, lighter weight and higher performance are achieved. Additionally, with this method, a large-size PCS at full capacity is required for the generator, but high efficiency is realized by applying an AT-NPC 3-level conversion circuit that incorporates Fuji Electric's power electronics technology in the PCS. (see "Permanent Magnet Synchronous Generator for Wind-Power Generation" on page 130.)

In consideration of applications to offshore wind power generation, the cooling system is characterized by the use of water cooling, rather than cooling with the outside air. FRT capability*7 is also provided as a standard feature.

Moreover, wind power output fluctuates from moment to moment, and the effect of such fluctuations on the power quality is an issue. To advance the introduction of wind power generation, Fuji Electric combines a storage cell and power stabilizer so that fluctuations in the output from wind power generation can be suppressed through control of the charging and discharging of the storage cell, and also applies a power stabilizer to increase the quality of the voltage and frequency of the power grid. (see "The Circuit and Control Technology in the Power Conditioner and Converter for Wind Turbine Systems" on page 124.)

6. Postscript

The global demand for electric power energy will increase greatly in the future, and accordingly, "energy creation" to produce electric power energy will play an important role. In order to realize a stable supply of electric power and a low carbon society, Fuji Electric remains committed to the pursuit of energy creation. Fuji Electric will continue to advance the research and development of large-scale thermal power generation and geothermal power generation, and to provide highly efficient, high performance and highly reliable power generation equipment. Renewable energy is environmentally friendly, does not emit CO_2, and is positioned as an important energy for achieving the best mix of energy. In the renewable energy sector, in addition to power generation capability, grid intercon-

***7: FRT capability**

Fault ride through (FRT) capability is, at the time of a three-phase short circuit or two-phase short circuit with the power grid, the ability to continue operation so as to output three-phase current within a specified range and to suppress power supply fluctuations of the grid, without the inverter quickly halting its output. The specified range indicates the duration of momentary line drop and the voltage drop range and is determined by each country.

nection technology and stabilizing technology are also important factors. Fuji Electric seeks to combine the power electronics technology and control technology at which it excels in order to build optimal systems.

Fuji Electric is also working to build smart communities for which further growth is anticipated. To build a smart community society, it is important to aggregate technologies for energy creation, energy savings, power electronics and energy optimizing control, information communication and the like, and Fuji Electric intends to use its collective strengths to contribute to society.

Reference

(1) International Energy Agency. World Energy Outlook 2012, Organization for Economic, 2012.

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Innovating Energy Technology