ENERGY FUTURE

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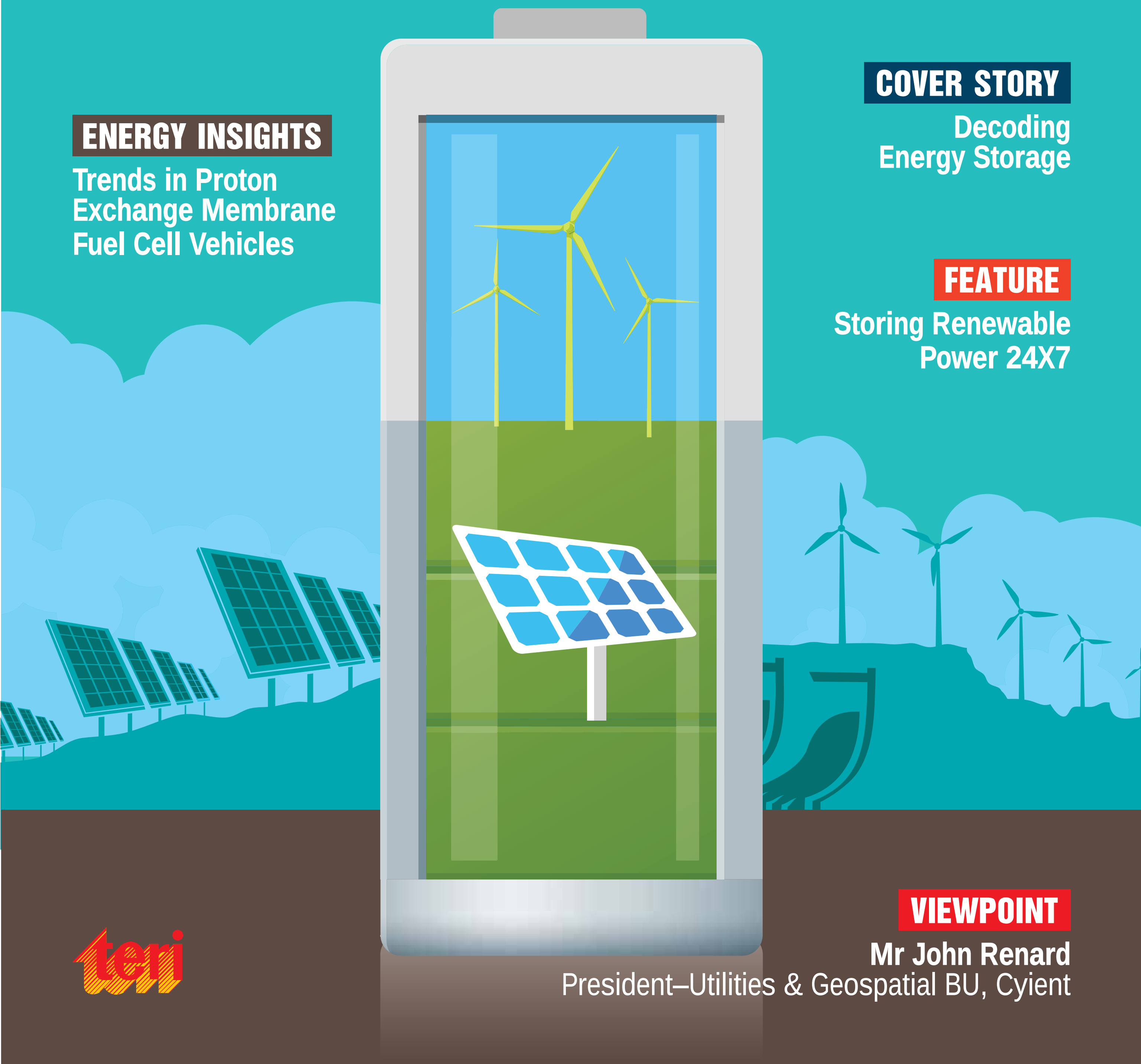

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COVER STORY

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FEATURE

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VIEWPOINT

Mr John Renard

President–Utilities & Geospatial BU, Cyient

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From the editor's desk...

In the electricity supply system, there are concepts such as *firm* power and *dispatchable* power. Essentially, these terms denote the ability of power generation plants to supply committed quantum and quality of electricity as per the market demands at any point of time. Conventional power, such as thermal and hydroelectric, is termed as *firm power* because it can be scheduled by the power system operators as per the loads. Variable renewable energy resources, such as wind and solar, on the other hand, constitute *infirm* power because of their inherent intermittency that is dependent on natural conditions rather than on man-made controls. And this is a critical factor for an efficient and balanced electricity supply network. As more and more grid-interactive wind and solar power plants come on stream, finely tuned grid integration and balancing also becomes more complex. And that is where energy storage comes into the picture. These energy storage modes comprise pumped hydro as well as chemical energy storage devices, such as batteries. The battery energy storage systems can be charged by solar or wind energy when generation is excess and the stored energy then can be used either to smoothen out the fluctuations, for grid balancing or for meeting the demand during the periods when solar or wind energy is not available. Even for off-grid solar or wind systems or for that matter, small solar devices, such as solar lanterns or home lighting systems, energy storage—normally the batteries—acts as the heart because while solar energy is available during the daytime, the requirements typically are during the evening.

As per REN21's *Global Status Report* 2018, 178 GW of renewable power capacity was installed worldwide in 2017. Solar PV accounted for nearly 55% of this while wind contributed to around 29%. In fact more solar PV capacity was added in 2017 than the net additions of fossil fuels and nuclear power combined. As is the case in India, RE bids continue to help make solar and wind power more competitive vis-à-vis conventional electricity. However, the real tipping point shall arrive when the combined costs of solar or wind power together with energy storage become comparable to, say, thermal electricity. However, there are certain encouraging trends. The Bloomberg New Energy Finance Report on Lithium- ion Battery Costs and Market forecasts that lithium-ion battery prices would continue to fall. The TERI report on *Transitions in Indian Electricity Sector 2017–2030* opines that if the costs of renewable electricity and energy storage systems continue to follow the expected trajectory, it could trigger transition to clean electricity in a big way. This transition in a sense will usher the new *Energy Future* for the global community!

Amit Kumar
Senior Director, Social Transformation, TERI

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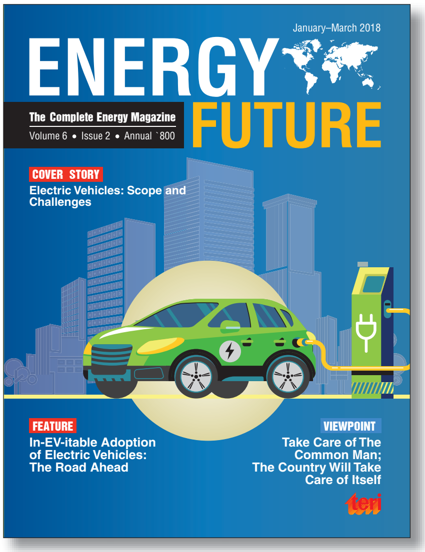

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Letter to the Editor

I truly liked reading the special issue of *Energy Future* on electric vehicles (EVs). I must say that one of the most important evolution in transportation technology has been that of the EVs—a sustainable solution to our current gasoline and diesel-fuelled vehicles. This new technology has enabled the auto industry to meet worldwide pollution standards. A very pertinent question has been raised in the feature article: Whether India is ready for the big transition to EVs or not? Obviously, in order to enable EV mobility in India, certain key challenges need to be addressed and a collaborative approach between India's public and private sectors is imperative.

Manmohan Pandey
Lucknow, Uttar Pradesh

"Apropos to the viewpoint section with Mr Sohinder Gill, I think he has satisfactorily answered a lot of questions on electric vehicles to a large extent. The government's statement of 'achieving an all-electric car fleet by 2030' may sound a bit ambitious but it is definitely a step in the right direction. Mr Gill is right when he says that we may not reach a 100% electric milestone but that does not mean that we should not aim for it. Other articles published in this issue are also noteworthy and highly informative. I also thank you for providing useful information about the 9th GRIHA SUMMIT 2017."

Iqbal M Azim
Ahmedabad, Gujarat

"The January–March 2018 issue of *Energy Future* with all the latest news, insightful articles, and events related to the energy segment are an eye opener for a lay reader like me. I particularly liked the eye-catching article title that read 'IN-EV-ITABLE ADOPTION OF ELECTRIC VEHICLES'. I mean it is creative as well as informative, to say the least. The author has succinctly explained the need and significance of EVs and also charts the present and future of EVs in India. She rightly feels that in future the international and Indian EV ecosystem requires more EV charging infrastructure facilities and this availability of charging stations will also help make EV a positive business venture."

Harshita Banerjee
Kolkata, West Bengal

"With reference to the Energy Insights article 'Ionic Liquids: Significance in Renewable *Energy Production*' published in the latest issue of *Energy Future*, I feel that it is a highly useful technical article for researchers and students who study about ionic liquids in their degree courses. The article published in the Solar Quarterly section is also quite edifying. I look forward to reading *Energy Future* every quarter to keep myself abreast of the latest developments in the energy sector. I also wish to associate myself with TERI and its research activities in the future. Let's see…"

Er. Vikram Dewan
Ambala, Haryana

Thank you very much for your encouragement. The editorial team of Energy Future will ensure that the magazine caters to your information and knowledge needs. We welcome your suggestions and comments to further improve our content and presentation.

Email: teripress@teri.res.in

Editor
Energy Future

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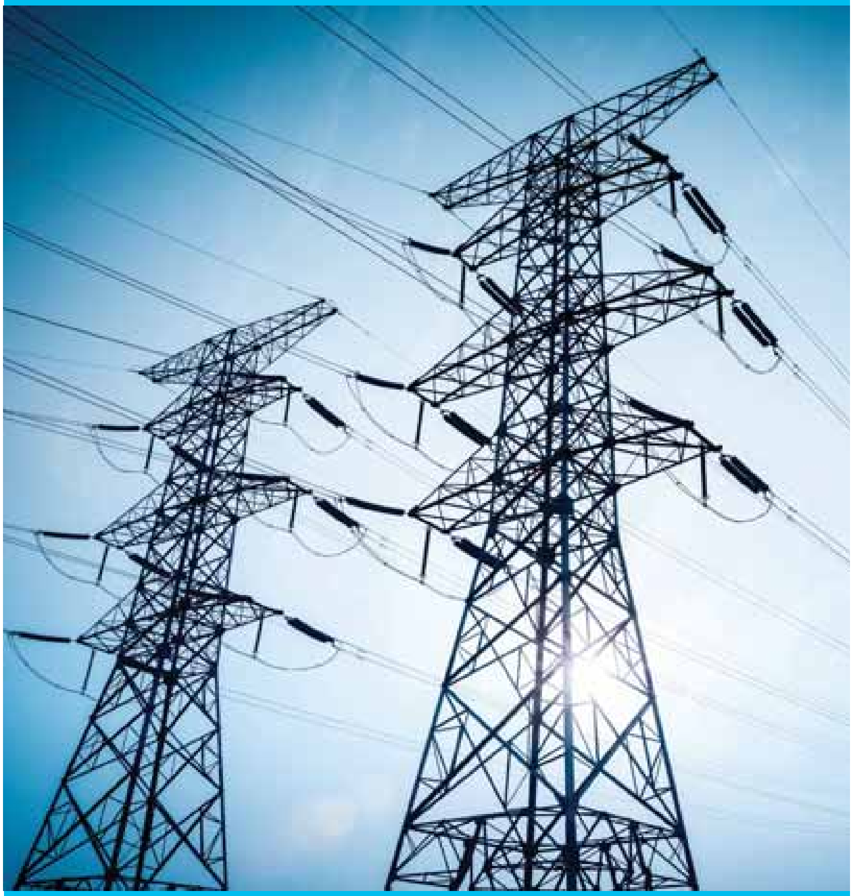
GOVT LAUNCHES PILOT SCHEME TO BUY 2.5 GW FROM POWER PLANTS NOT HAVING PPAs



State-run Power Finance Corporation (PFC) said the government has launched a pilot scheme to procure 2,500 MW electricity for 3 years under medium term arrangement from commissioned power plants without power purchase agreements (PPAs). The main purpose of the scheme is to revive commissioned power plants which are unable to sell electricity in the absence of valid PPAs. These plants can bid for power supply under the scheme. The PFC arm, PFC Consulting Ltd has been appointed as the Nodal Agency and PTC India Ltd as the Aggregator. PTC India will sign three-year (mid-term) agreement for power procurement with successful bidders and Power Supply Agreement with the Discoms (distribution companies).

Under the scheme, a single entity can be allotted maximum capacity of 600 MW. The scheme assures a minimum off take of 55% of contracted capacity. The tariff will be fixed for three years without any escalation. EF

Source: The Times of India

HERO FUTURE ENERGIES SETS UP COUNTRY'S FIRST HYBRID RENEWABLE POWER PLANT

Hero Future Energies has commissioned the country's first large-scale hybrid renewable energy project—a combination of sun and wind power—in Karnataka's Raichur district. The company has added a 28.8 MW solar project to an existing 50 MW wind project set up two years ago. Also, both wind and solar are 'infirm' sources of power in that their supply varies according to the speed of the wind or the intensity of solar radiation. By combining the two, the project can supply steady power for a longer period in a day than standalone wind or solar plants, and improve its overall plant load factor (PLF). Wind speeds are usually highest early in the morning and at night, while sunshine is available only during the day. EF

Source: The Economic Times

DIU SMART CITY FIRST IN INDIA TO RUN ON 100% RENEWABLE ENERGY DURING DAY

The Diu Smart City has become the first city in India that runs on 100% renewable energy during the daytime, setting a benchmark for other cities to follow, according to an official release. Diu had been importing 73% of its power from Gujarat till last year, it added. The city has developed a 9 MW solar park spread over 50 ha rocky barren land, besides installing solar panels on the rooftops on 79 government buildings, generating 1.3 MW annually, the Housing and Urban Affairs Ministry's release said. Diu also offers its residents a subsidy of `10,000-`50,000 for installing 1-5 kW rooftop solar panels. The city is saving about 13,000 tonnes of carbon emissions every year and due to low-cost solar energy, power tariffs have been cut in residential category by 10% last year and 15% this year, the release said. EF

Source: The Economic Times

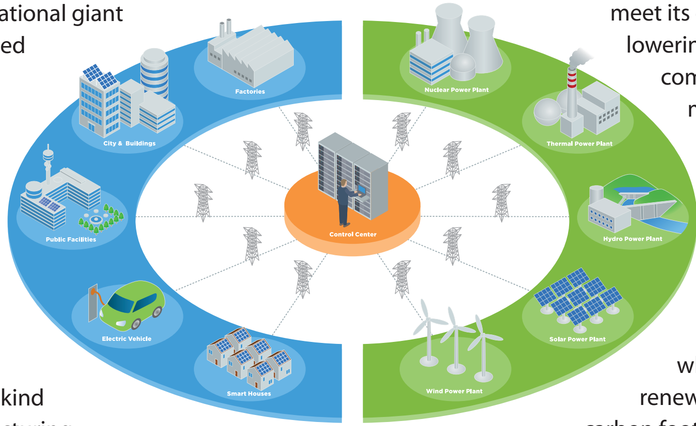
MAHARASHTRA'S TOY TRAIN STATIONS TURN GREEN

The four stations of Central Railway's Matheran Hill Railway in Maharashtra's Raigad district have turned "green" with the installation of solar power and wind energy plants. Sunil Udasi, the Chief Public Relations Officer, Central Railway, said in a statement that on the installation of Green Energy System, the generation capacity of each system at four stations—Jummapatti, Waterpipe, and Aman Lodge is 75-80 kWh, while at Matheran, it is 680–690 kWh per month. All these four stations are now provided with a solar power plant of capacity 500–1000 Wp and windmill of capacity 6.1 kWp at Matheran including energy efficient LED lights and fans. The electric supply from the renewable sources will bring down the hill railway station's power bill drastically resulting in savings of `2.07 lakh per year, besides reducing its carbon footprints. The Matheran Hill Railway is narrow-gauge heritage railway in Maharashtra. A delight to the tourists and the route to the summer destination for Mumbaikars, the line covers a distance of 21 km, cutting a swathe through dense forest in the Western Ghats from Neral to Matheran. EF

Source: The Economic Times

INDIA'S FIRST INDUSTRIAL SOLAR MICRO-GRID COMMISSIONED IN GUJARAT

Swedish-Swiss multinational giant ABB has commissioned India's first industrial solar microgrid at its Vadodara manufacturing facility in Gujarat. The Vadodara factory is ABB's largest facility in India with over 3,000 employees and among its biggest manufacturing hubs in the world. "The microgrid is the first-of-its-kind to be installed at a manufacturing campus in India and will harness the area's abundant solar energy supply to help the expanding factory meet its growing electricity needs, while lowering its carbon footprint," the company said in a statement. The microgrid's rooftop photovoltaic field and its battery-energy storage system will support the factory's productivity and enable green power supply. A sophisticated control and automation system serves as the brain of the microgrid which ensures maximizing renewable energy use. The facility's carbon footprint is expected to be reduced by around 1,400 tonnes of carbon dioxide per year. EF



Source: The Economic Times

BSES INSTALLS FIRST GRID-CONNECTED ROOFTOP SOLAR PLANT

Delhi electricity distribution company (DISCOM) BSES-Rajdhani installed the first grid-connected 100 kW solar rooftop plant in a residential housing society in Dwarka locality of Delhi as part of its Solar City Initiative to "solarize" the area. Shiv Bhole Cooperative Group Housing Society (CGHS) in Dwarka has become the first such housing society to install a 100 kW grid-connected rooftop solar plant, a BSES release said. "Each of the 60 flats will save around `4,500 annually in their electricity bills, while the solar plants will be able to offset around 32% of a resident's annual carbon emission," it said. The Solarise Dwarka initiative, launched in January 2018, is being implemented by BRPL in collaboration with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ India) under its Indo-German Solar Partnership project, it added. EF

Source: Business Standard

GUJARAT BECOMES FIRST STATE TO LAUNCH SUBSIDIZED PNG FOR BPL FAMILIES

Gujarat became the first state in the country to offer subsidized piped natural gas (PNG) to households falling under the below poverty line (BPL) in Bharuch. In what is being launched a pilot project, the new PNG/LNG Sahay Yojana may see replication in other parts of Gujarat as well as other states. Under the scheme, Gujarat government will provide a one-time

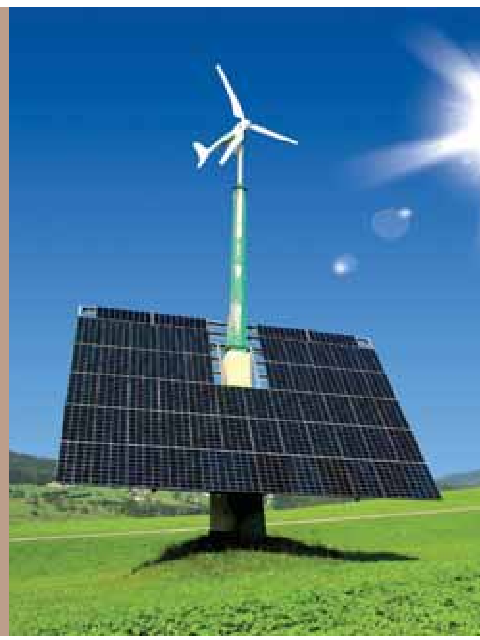
subsidy of `1,600 for each connection or household, apart from `1,725 as loan to consumers seeking new PNG connection. For the subsidy, the state government is learnt to have made a provision of nearly `720 million for the subsidy to the beneficiaries. An extension of the Ujjwala Yojana, the scheme is being seen as a move to replace kerosene and offer cleaner fuel for BPL households. According to state government officials, the households in the Bharuch area have been selected on the basis of BPL as well as the state's own Antyodaya Anna Yojana (AAY) categories.

Source: Business Standard

GOVERNMENT ANNOUNCES NATIONAL WIND-SOLAR HYBRID POLICY

With an aim to boost renewable power generation, the government announced a national wind-solar hybrid policy, which seeks to promote new projects as well as hybridization of the existing ones. The government has set an ambitious target of achieving 175 gigawatt (GW) of installed capacity from renewable energy sources by 2022, which includes 100 GW of solar and 60 GW of wind power capacity. The policy provides for a comprehensive framework to promote large grid-connected wind-solar photovoltaic (PV) hybrid system for optional and efficient utilization of transmission infrastructure and land, thereby reducing the variability in renewable power generation and achieving better grid stability, the Ministry of New and Renewable Energy said in a release.

Source: The Economic Times



ASIA LEADS THE CHARGE IN GROWTH OF RENEWABLE ENERGY

In 2017, Asia accounted for nearly two-thirds of the worldwide increase in renewable energy generating capacity, according to a report published in April by the International Renewable Energy Agency (IRENA). IRENA, an intergovernmental organization based in Abu Dhabi, reported that global renewable energy capacity in 2017 was 2,179 gigawatts (GW)—greater than the capacity of world's coal powered plants, and approximately eight times Japan's entire energy generation capacity—an increase of 8% compared with the previous year. For Asia as a whole, including Central Asia, renewable energy capacity has nearly doubled over the past five years, reaching 918 GW in 2017. China and India were the biggest contributors to the increase. Asia's third-largest producer of renewable energy is Japan, with a total capacity of 82 GW, rising 7 GW last year. Hydropower is driving renewable energy growth in Vietnam, Asia's fourth-largest producer, with about 18 GW of capacity. The growth rate for renewable energy was rapid in Mongolia and Cambodia, albeit from a low base. EF

Source: NIKKEI Asian Review

CHINA DEVELOPS BATTERY TO STORE RENEWABLE ENERGY

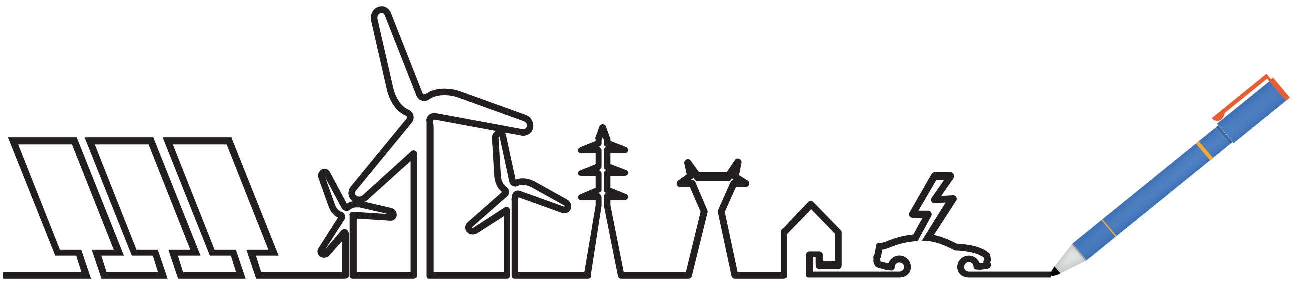
Chinese scientists have developed a lead carbon battery for storing power generated from solar panels and windmills and claimed that with such devices, the electricity supply is stable for use. An energy storage system with the batteries was piloted in Dalian Institute of Chemical Physics in northeast China's Liaoning Province, Xinhua news agency reported. There are 46 streetlights and landscape lights using solar energy for power at the institute. Each lamppost has a solar panel to generate power, which is sent to a battery equipped under the post. A fully-charged battery can power a streetlight for more than 23 hours, the scientists claimed. In the pilot, the battery has shown a 100% recharge rate and safety performance. The team has applied for 10 national patents for the battery. EF

Source: The Economic Times

COSTA RICA TO BAN FOSSIL FUELS AND BECOME WORLD'S FIRST DECARBONIZED SOCIETY

Costa Rica's new president has announced a plan to ban fossil fuels and become the first fully decarbonized country in the world. Carlos Alvarado, a 38-year-old former journalist, made the announcement to a crowd of thousands during his inauguration."Decarbonization is the great task of our generation and Costa Rica must be one of the first countries in the world to accomplish it, if not the first," Mr Alvarado said. Symbolically, the president arrived at the ceremony in San Jose aboard a hydrogen-fuelled bus. Costa Rica already generates more than 99% of its electricity using renewable energy sources, but achieving zero carbon transport quickly—even in a country well-known for its environmental commitment—will be a significant challenge, experts say. EF

Source: The Independent



SEA OF SOLAR PANELS TURNS MEXICAN DESERT GREEN

With 2.3 million solar panels—covering the equivalent of 2,200 football fields in the arid northern state of Coahuila—the Villanueva power plant, built by Italian energy company Enel, is part of Mexico's push to generate 43% of its electricity from clean sources by 2024. Arrayed across the sand in seemingly endless rows that stretch to the horizon, the solar panels are made to turn in tandem with the sun, like a giant field of shimmering metallic sunflowers. The $650-million project is due to produce 1,700 GW hours when fully operational—enough to power 1.3 million homes. The Villanueva plant is the largest solar project in the world outside China and India. EF

Source: The Economic Times

WORLD BANK INCREASES SUPPORT FOR CLEAN ENERGY IN BANGLADESH

The World Bank approved $55 million to expand use of clean renewable energy in rural areas of Bangladesh where grid electricity cannot reach easily. The additional financing to the Second Rural Electrification and Renewable Energy Development (RERED II) Project will install 1,000 solar irrigation pumps, 30 solar mini-grids, and about 4 million improved cookstoves in rural areas. The project, including the additional financing, will enable about 10 million people living in villages, shoals, and islands to access electricity and use energy efficient cookstoves. These interventions will help the country reduce carbon emissions.

The financing will also help increase use of solar irrigation pumps, a low-cost technology that is well-suited to the country's flat terrain and abundant sunshine. This switch from diesel pumps will decrease greenhouse gas emissions and save foreign exchange by reducing the government's subsidy on diesel imports. EF

Source: Modern Diplomacy

THIS COULD BE THE BIGGEST ADVANCE IN ALUMINUM PRODUCTION IN 130 YEARS

Apple, the largest publicly traded company in the world, joined a major collaboration that could change how it gets one of the key components that makes its ubiquitous gadgets look so sleek: aluminum. And it is looking as though, simply by seeking out a greener component for iPhones and Macs, the tech giant just might push an entire industry in a new direction.

Along with major US aluminum producer Alcoa and multinational mining behemoth Rio Tinto, Apple announced a collaboration in Canada to fund a technology that, the companies say, can remove carbon dioxide emissions from the high-temperature smelting process that goes into making aluminum. Alcoa and Rio Tinto also announced a joint venture named Elysis to scale up and commercialize the technology, in which the government of Canada and Apple will invest.

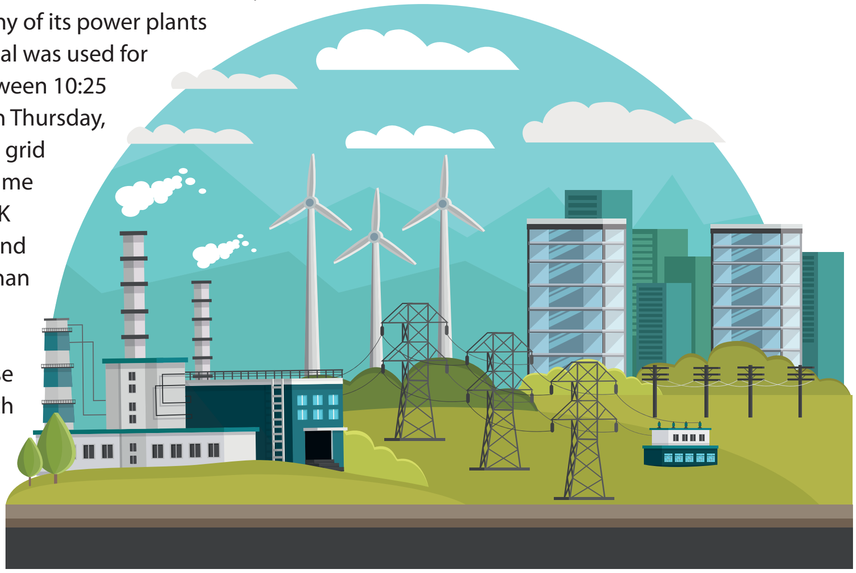
Overall, the production of aluminum accounts for about 1% of total global emissions of carbon dioxide—making it a surprisingly large player. The process also uses up a lot of energy because of the heat and electricity required. But it has been done in more or less the same way since 1886, when the Hall-Héroult process of aluminum smelting was invented. EF

Source: The Washington Post

THE UK JUST WENT 55 HOURS WITHOUT USING COAL FOR THE FIRST TIME IN HISTORY

Coal, which fuelled the world's biggest economies for more than a century, is increasingly losing out to renewables. The latest example of how one of the dirtiest fossil fuels is being squeezed out of the market came in Britain, which went for a record 55 hours without any of its power plants producing electricity by burning coal. No coal was used for power generation by stations in the UK between 10:25 p.m. in London on Monday until 5:10 a.m. on Thursday, in the third week of April 2018, according to grid data compiled by Bloomberg. At the same time wind turbines produced more power. The UK was an early adopter of renewable energy and has more offshore wind turbines installed than any other country. It also has fields of solar panels that are meeting more and more demand as old traditional power plants close permanently. The government aims to switch off all coal plants by 2025 and has given renewables priority access to the grid. The previous record of 40 coal-free hours was set in October 2017. EF

Source: Bloomberg



SOLAR ENERGY CAN HELP SOLVE AUSTRALIA'S WATER CRISIS, SAYS NEW REPORT

Australia can help solve its water crisis by optimizing use of water-friendly solar energy, a new report concludes. Because solar power generation consumes minimal to zero water, it beats water-hungry coal-fired power production in terms of conserving an increasingly precious natural resource. That's the verdict of the World Resources Institute (WRI). Its new report points out that solar energy is therefore not only clean, but critically important in water conservation.

And because energy production accounts for around 10% of the world's water consumption, solar power can play a crucial role in tackling the world's growing water shortage. EF

Source: Energy Matters

DECODING ENERGY STORAGE

On April 22, 2016, the entire world came together to sign probably the single most diplomatic agreement in the history of human civilization in order to fight the ultimate tragedy of climate change in Paris (France). With 195 countries signing the Paris Agreement, there is now a global shift of moving towards cleaner environmental and sustainable practices which involves decarbonizing key segments of the energy market, such as transport and the power sector. In this context, **Rashi Singh**, through this article, decodes energy storage as an effective tool to achieve constructive integration of renewable energy and obtain the benefits of clean and sustainable energy supply. The article also sheds light on the challenges and the global scenario for energy storage systems.

Introduction

In the modern day world, electricity has become synonymous with energy and is imperative to our day-to-day working. Electricity is the prototypical just-in-time product due to the limited means to economically store it on a large scale. As such, electricity must be consumed as soon as it is produced. With a consumption of about 25,000 Terra-watt hours[1] worldwide, presently a huge chunk, about 67%,[2] of electricity is derived from fossil fuels. This makes the electricity sector the 'dirtiest' of all and alone responsible for 30% of the greenhouse gas emissions[3] followed by the transport sector.

However, in the backdrop of the end of fossil fuel energy and the alarming levels of greenhouse gases (GHGs), a paradigm shift in the energy landscape towards greater use of renewable energy in the form of wind and solar for energy generation is underway. Although, this type of power generation is more sustainable, it makes the delivery of reliable power, on demand, a major challenge.

Need of the Hour

A secure, reliable supply of electricity 24 hours of the day along with judicious use of renewable energy resources to reduce reliance on non-renewable fossil fuels, such as oil and gas, is the need of the hour. However, complete reliance on renewable energy resources for all energy needs is not always possible since they are highly variable and intermittent. The variability of solar and wind power makes it hard for electricity providers to integrate them into the

> **“We are seeing a global trend towards greater energy independence, as consumers seek to acquire active control when it comes to their energy needs.”**

[1] https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf

[2] http://www.tsp-data-portal.org/Breakdown-of-Electricity-Generation-by-Energy-Source#tspQvChart

[3] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

electricity grid. Grids need to be reliable and stable and continuously balance the supply and demand of electricity.

Grid demand not only varies substantially minute-to-minute but also hourly (night-time vs early evening) and seasonally (summer vs winter). Over the years, energy production that strives to match the user demand in the most economical way possible has developed. However, we are witnessing a global trend towards greater energy independence, as consumers seek to acquire active control when it comes to their energy needs. There has been a phenomenal growth in use of solar rooftops, solar water heaters, and other 'behind-the-meter' generation resources. These 'prosumers' have the potential to quickly change how grids are managed and priced.

Given the sharp and often rapid decline in the cost of renewable power generation technologies in recent years, the electricity sector has made concrete progress on decarbonization. Globally, the solar sector is witnessing historically lowest tariff rates. With lowest of tariff `2.44/unit, India has seen a 73% decline in solar tariff since 2010.[4] Renewable power deployment, however, needs to accelerate. Various countries have set their individual goals to decarbonize their power sector, in compliance with the Paris Agreement, as well as the end-use sectors, such as direct energy usage in industry, transport, and residential and commercial buildings, also need to speed up, considering how progress is lagging in these areas.

Opportunity for Storage

As new technologies and usage increases, the value of energy and the means of storing excess and waste energy will become increasingly important. Excess energy produced by wind and solar generators is not usable without the means to store it. This is where energy storage plays a major role in terms of capturing the energy produced at one time for use at a later time. Energy storage serves as a bridge between the limited, variable generation capability of energy sources and the highly variable, cyclical grid demand and can be implemented as a buffer to match the available generation to the variable user demand. Storage based on rapidly improving batteries and other technologies will permit greater system flexibility—a key asset as the share of variable renewable electricity (VRE) increases. The technology continues to prove its value to grid operators around the world who must manage the variable generation of solar and wind energy.

The development and monitoring of energy storage systems is important for the future smart grids since energy storage is a crucial tool for enabling the effective integration of renewable energy and unlocking the benefits of local generation and a clean, resilient energy supply. Battery storage in solar home systems and off-grid mini-grids, meanwhile, are decarbonizing systems that were heavily reliant on diesel fuel while also providing clear socio-economic benefits. It enables effective, 24-hour off-grid solar home systems and supports 100% renewable mini-grids and micro-grids.

Energy storage can directly drive rapid decarbonization in key segments of energy use. After the electricity sector, the second high carbon-emitting sector is transportation. The GHG emissions from the transport sector primarily derive from burning fossil fuel for cars, trucks, ships, trains, and aeroplanes. Over 90% of the fuel used for transportation is petroleum based, which includes gasoline and diesel. Electricity storage makes possible a transportation sector dominated by electric vehicles (EVs). In transport, the viability of battery electricity storage in EVs is improving rapidly. Decarbonizing the transport sector has for long been a challenge but is now gathering momentum with the scale-up of EV deployment and the drive to lower battery costs. The cost of an EV battery has fallen by 73% between 2010 and 2016 (BNEF 2017), and the total stock of electric cars reached 2 million after having gone beyond the level of 1 million in 2015 (OECD/ IEA 2017). The two- and three-wheel EV numbers have surpassed 250 million globally while there now are 300, 000 electric buses in China alone. Following rapid cost reductions and significant improvements in capacity and efficiency,

[4] Mercom Capital Group report

Energy storage has been identified as one of the topmost important technologies by countries, such as China, Japan, and the USA in their national strategies/plans. From helping in integrating renewable energy into the grid to standalone mini-grids, energy storage has various major applications that align with sustainable development. Powering standalone telecom towers, energy arbitrage, transmission and distribution network deferrals, and extending support to the power grid (ancillary services) are the other major areas where the application of energy storage is vital. Technology, economics, and government policy are coming together to unleash a new force in global electricity in the form of the global energy storage market. Electricity storage will be at the heart of the energy transition, providing services throughout the electricity system value chain and into the end-use sectors.

the global energy sector is captivated by the promise of deploying energy storage alongside renewables. Storage is promoted as the 'game-changer' which could contribute to solving the volatility challenge of wind and solar electricity generation. According to the International Renewable Energy Agency (IRENA), electricity storage will be vital to the next phase of energy transition. Along with firming solar and wind power generation, it will allow sharp decarbonization in key segments of the energy market.[5] The estimated capacity[6] of energy storage systems (ESS) through 2020 comprises the highest share from the transportation sector (~14%) followed by the solar sector (~13%), as is visible in Figure 1.

Energy storage plays a key role in achieving ambitious environmental policy objectives by facilitating greater connection of intermittent renewable generation. It helps in reducing and/

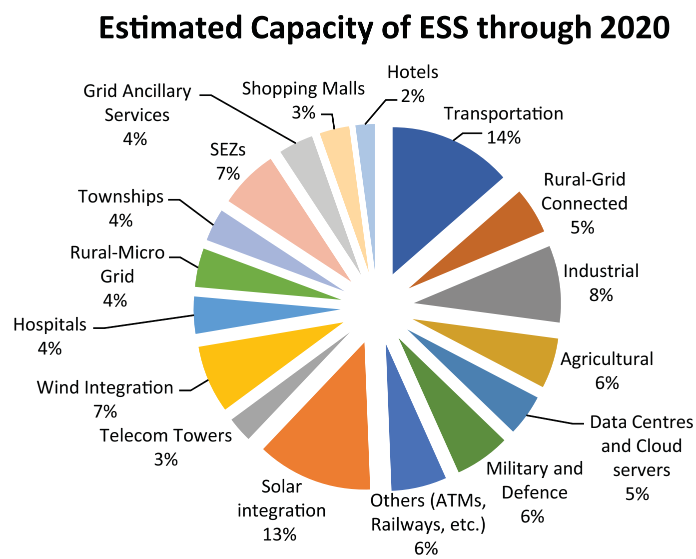


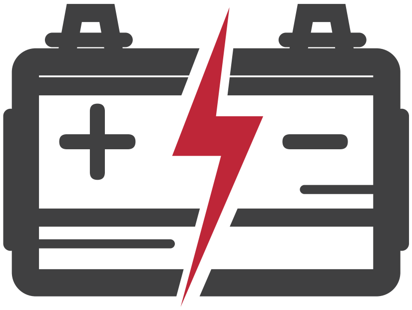
Figure 1: ESS capacity through 2020 in various sectors

or delaying the investments required in creating new transmission and distribution infrastructure as well as augmentation of existing infrastructure.

Getting acquainted with the technologies

The concept of energy storage with multiple technologies and applications

[5] IRENA report on 'Electricity Storage and Renewables: Costs and Markets to 2030,' October 2017
[6] ESC Global Energy Storage Market report 2015



has been around since the mid-1700s. Notable scientists, such as Benjamin Franklin, Alessandro Volta, and Michael Faraday, have worked upon its earliest development. Pumped hydro energy storage has dominated energy storage for over a century. The recent growth of EVs and the need to integrate renewable power technologies, such as solar and wind, are driving huge investments in the development of battery technologies. Today, the highest commercial interest lies in battery storage.

Based on scientific categorization, storage technologies can be categorized and clustered into mechanical, thermal, chemical, electro-chemical, and electrical storage. These are further categorized on the basis of their key characteristics, such as rated power, charging-discharging time, and energy capacity. Table 1 provides an overview of the various available energy storage technologies based on technology type.

The recent advances in electrical energy storage technology and methods manifest, for instance, in the form of batteries and pumped hydroelectric storage plants while compressed air energy storage (CAES), flywheels, superconducting magnetic energy storage (SMES), and super-capacitors are fairly contemporary. Figure 2 describes the maturity level of various energy storage technologies available so far.

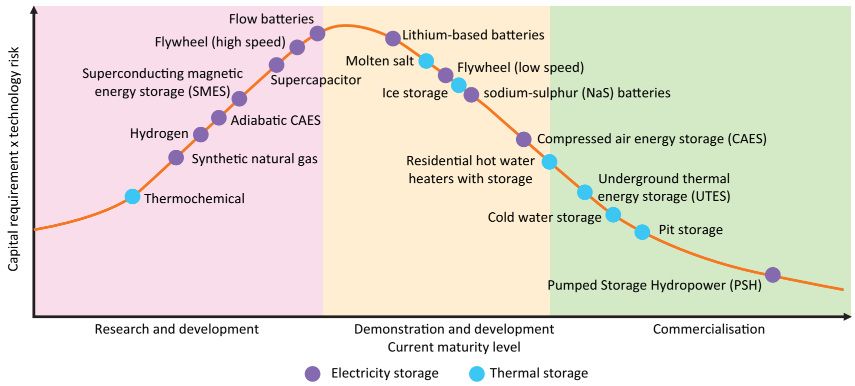


Figure 2: Maturity level of energy storage technologies

Source: Renewable Energy Agency

Chemical energy storage, most commonly applied in batteries, is the world's most prolific form of energy storage. However, there are several drawbacks to batteries for large systems, including the cost, short life span, and disposal concerns. The next most common form of energy storage is pumped hydroelectric. This method has been successfully applied to large utility scale projects in the 50 MW to 2 GW power range, although it is severely limited by geography and has a comparatively longer gestation period. Compressed air energy storage is an emerging option for storage, also finding its best application in large utility scale projects. Flywheels, superconducting magnetics, and super-capacitors are generally suitable for lower energy applications, although somewhat high power output can be attained when many devices are combined. These devices are generally quite expensive. No cost-effective and efficient energy

> **"Following rapid cost reductions and significant improvements in capacity and efficiency, the global energy sector is captivated by the promise of deploying energy storage alongside renewables."**

Table 1: Overview of various energy storage technologies

Technology Type	Subtechnology Type
Electro-chemical	Electro-chemical capacitor, lithium-ion battery, flow battery, vanadium redox flow battery, lead-acid battery, metal air battery, sodium-ion battery
Electro-mechanical	Compressed air storage, flywheel
Chemical	Hydrogen storage, liquid air energy storage
Pumped hydro storage	Closed-loop pumped hydroelectricity storage, open-loop pumped hydroelectricity storage
Thermal storage	Chilled water thermal storage, concrete thermal storage, heat thermal storage, ice thermal storage, molten salt thermal storage

Source: International Renewable Energy Agency Report[5] storage method for large-scale needs has yet emerged from these advances in technology.

Not one size fits all

Each of these technologies has specific applications based on their key characteristics. For example, a storage technology with fast charging-discharging time is ideal for managing variability, due to renewable energy, of the grid that occurs over a matter of few seconds to a minute, while for the application of energy arbitrage, a storage technology with larger energy capacity, and not necessarily fast discharging, is required.

Storage not only helps in making the grid more efficient by helping to incorporate more distributed and variable resources, such as wind and solar, but also by making the grid more cost efficient. Future energy systems will rely on a large array of services based on effective and economical electricity storage. The myriad of services that can be provided with electric storage, with varying performance requirements, suggests an important role for many different storage technologies. Although, lithium-ion (Li-ion) batteries are likely to dominate the EV market, this is not necessarily going to be the case in stationary applications.

The varying requirements of the range of services provided by electricity storage and the different performance characteristics of each group of electricity storage technologies implies that a diverse group of storage technologies will prosper. In terms of the market of energy storage for stationary applications through batteries up to 2030, there is a significant potential for growth in applications behind-the-meter, notably in order to increase the self-consumption share of the output of rooftop solar PV[7] and can make up to 60%–65% of the installed capacity battery energy storage in 2030.

Challenges

Though energy storage can provide a number of solutions to help us meet our ends, it still has to overcome certain barriers before it can be established in entirety. The most significant barrier to its deployment is the high capital cost. In order to accomplish large-scale deployment of energy storage, the economics has to first make sense. Lead-acid batteries and pumped hydro storage are on the cheaper side with capital cost around `65–`260 per watt while the costlier options such as flow batteries and sodium sulphur batteries cost around `195–`300 per watt. CAES

has the largest range of cost from `50 per Watt to `600 per watt depending on its size and application.[8]

Several recent deployments indicate that capital costs are decreasing and energy storage may be the preferred economic alternative in certain situations. For example, the cost of Li-ion batteries has fallen by as much as 73% between 2010 and 2016 for transport applications. Li-ion batteries in stationary applications have a higher installed cost than those used in EVs due to the more challenging charge/discharge cycles that require more expensive battery management systems and hardware. Benefitting from the growth in scale of Li-ion battery manufacturing for EVs, the cost could decrease in stationary applications by another 54%–61% by 2030. This would reflect a drop in the total installed cost for Li-ion batteries for stationary applications to between USD 145 per kilowatt-hour (kWh) and USD 480/kWh,[9] depending on battery chemistry. Whilst pumped hydro storage, which is the largest single source of electricity storage capacity today and accounts for more than 99% of bulk storage capacity worldwide: around 127,000

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7 IRENA report on 'Battery storage for renewables market status and technology outlook,' January 2015

8 'Global Energy Storage Market Overview and Regional Summary' by Energy Storage Council

9 IRENA report on 'Electricity storage and renewables: Costs and markets to 2030,' October 2017

MW across 200 large sites globally, is a mature technology with site-specific cost. There is little potential to reduce the total installed cost from a technology perspective; lead times for project development tend to be long, and it is not as modular as some of the new and emerging electricity storage technologies.

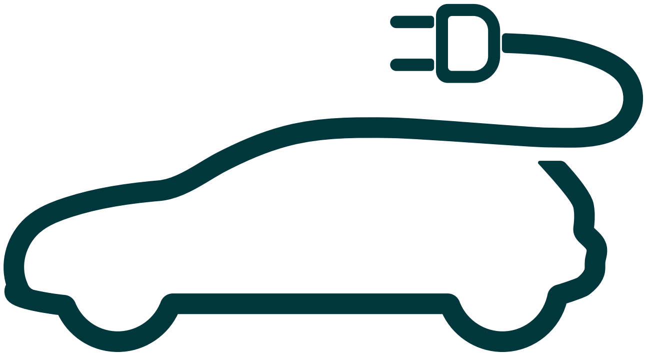
Other storage technologies also offer large cost reduction potential. For example, flow-batteries, although, presently have high upfront investment costs compared to other technologies, these batteries often exceeded 10,000 full cycles, enabling them to make up for the high initial cost through very high lifetime energy throughputs. They also offer valuable operational advantages, since they work at ambient temperatures, and their power and energy storage characteristics are independently scalable. Also, technologies such as flywheels could see their installed cost fall by 35% by 2030; while CAES, although based on a combination of mature technologies, could see a 17% cost decline by 2030. Although, there are sufficient studies that suggest that the cost of storage is subjected to decline, a number of other market and regulatory barriers persist, limiting further deployment. These barriers can be categorized into regulatory barriers, market or economic barriers, utility and business model barriers, cross-cutting barriers, and technology barriers. Other barriers, following the issues of uncertainty as being the key drivers of risk associated with adaptation of energy storage technology may also prevent the consideration of energy storage resources, such as:

- Technical capabilities, life-cycle performance, and longevity of energy storage resources are still not well understood by many stakeholders
- Lack of strong policy push, standards and regulations for energy storage
- Lack of charging infrastructure, pricing signals, and smart meters to monitor and control the energy storage participation into the grid
- Environmental regulations, when and if the government or the environmental protection agencies will implement these, and what form they will take
- Uncertainty in economic health that leads to variability in demand and energy prices
- Regulatory protocol changes: market mechanisms, accounting standards, renewable energy mandates, and fuel restrictions.

The Global Market

In the developed economies, such as the USA where the infrastructure is pretty dated, this can be a substantial benefit. For example, as per the US Department of Energy, about 70% of the transmission lines are 25 years or older, more than 70% of power transformers are 25 years or older, and about 60% of the circuit breakers are 30 years or older. In the decades to come, it is anticipated that the need for grid reliability and resiliency shall increase as a result of disruptions caused by severe weather events and other challenges, such as cyber security threats. It is also integrating large capacities of variable renewable energy resources into its grid. Storage, coupled with renewable and distributed generation, offers a logical fit for making the traditional grid more reliable and resilient. The USA, being a leader in energy and technology, has the largest market for energy storage, both by number of projects and by installed capacity, for every imaginable application and technology of storage. While in the European nations, there has been a drastic shift from coal and oil to renewable energy resources in the past couple of decades. Germany has been a front-runner in solar power globally with its innovative policies and

> **“The United States, being a leader in energy and technology, has the largest market for energy storage, both by number of projects and by installed capacity, for every imaginable application and technology of storage.”**



incentive programmes while countries, such as Sweden, Denmark, etc., are very close to achieving a 100% renewable grid. At the same time, there has been an exponential rise in the consumer-side generation throughout Europe, primarily through solar rooftops. Hence, apart from facing the inherent issues of variability that is associated with renewables to achieve grid stability and avoid renewable curtailment, there is scope for a large market for energy storage for consumer-side consumption in European nations.

China, too is similar to India in the context of its large energy demand and the energy sector scenario. It too has ambitious goals with respect to RE integration to replace its large coal fleets coupled with transmission infrastructure restrictions and grid reliability issues. It is one of the largest potential markets for energy storage technology. It has already taken a lead in EV deployment and manufacturing of battery storage. The China Energy Storage Alliance (CNESA) issued a white paper which discusses the developments within the country's energy storage market. According to CNESA, the Chinese energy storage market grew to reach an annual growth rate of 86% in 2016 as stakeholders in the energy sector realized the commercial value of energy storage within their operations. The renewable energy-grid integration segment accounted for 55% of all energy storage projects deployed in 2016 with the connection of distributed energy resources with grid networks being the fastest growing sector amongst other sectors. A major contributor to sector growth is the increase in support from national regulatory authorities through the drafting of new policies paving way for an increase in investments towards research, development, and implementation of existing and new energy storage technologies. Energy storage has been approved as the key towards China stabilizing its grid network through balancing traditional power generators, increasing integration of renewable energy resources with grid systems and expanding the portfolio of distributed energy resources.

While, other large economies are struggling to replace their 'dirty' generation resources with RE or to manage their grid reliability, India being a power deficit country has altogether a different issue. We have chosen to build our upcoming generation fleet with cleaner, more sustainable resources to meet our energy needs. The energy transition in India cannot avoid large scale deployment of storage. The revolution has already started and what is left to see is as to when and how storage will become the part of our energy scenario.

Energy Storage Market in India

India is one of the fastest growing economies in the world, with current electricity generation capacity of 330 GW to meet the needs of over 1.3 billion people. The Indian population is estimated to grow by 2 billion people by 2050; electricity demand is envisaged to be approximately two-fold by 2050. The power sector is at the brink of a major transformation as more stakeholders are migrating away from traditional sources of generation towards cleaner and sustainable energy resources, thus resulting in steep surge in renewables generation. The government has planned to integrate 175 GW of renewable energy by 2022 out of which 160 GW comes from solar (100 GW) and wind (60 GW). As discussed earlier, renewables are intermittent and variable in nature, reeling the stability of grid. Increasing renewable penetration requires a bee line solution to balance variations in grid. In the same way that transmission lines ascertain where electricity is consumed, energy storage influences when it is consumed.

In recent years, the policy initiatives are focussing in improving the health of power systems in India and have resulted in the growth of about 148% of the installed capacity in 2007 in the last decade, and the government has set the target of 24x7 power supply by March 2019. Government initiatives like Saubhagya ensuring last mile connectivity to rural households are pushing the envelope of microgrids in India. Micrograids are driving force for energy storage in China and the USA. The USA has highest number of microgrids followed by China. Microgrids can be a leading factor to encourage storage penetration in India as well. Decarbonizing the transportation sector is one of the top priorities for India and the Indian government has envisaged 'all-electric mobility markets' by 2030. Nearly $3.5 billion has been allocated to support EVs in India to 2022. However, India is still debating whether to leave the matter to the market forces or to use its policy tools to set-off the EVs in the market. As a factor of all the plans discussed earlier, India offers a concomitant market for energy storage systems. At present, the emerging consensus is that energy storage is the pivotal technology that will reshape the energy sector by enabling widespread adoption and grid-integration of renewables, provide grid services, empower consumers to have more control over their energy use, and help decarbonize the power and transportation sector.

The energy storage market in India is in its infancy with significant upside market potential. India has pumped hydro storage facilities with a total of just 7,000 MW of installed capacity. Apart from these facilities there are also few other utility scale storage projects currently operating in India. Recent Industry report by 'Electronics For You' shows that existing capacity of batteries in our homes used for power back up stands above 68 GW hours* in the form of lead-acid batteries and this existing storage might be utilized as demand-side resource by retrofitting the inverter technology to allow bidirectional power flow to the grid and back.

NITI Aayog, in its report on 'India Energy Storage Mission', has emphasized on focussing on manufacturing of energy storage technologies within India. Considering the projected scale of its domestic market it quotes that, "India could support global-scale manufacturing facilities and eventually become an export hub for battery production". It also mentions that the Indian EV market alone could help decline the global battery prices as much as by 16%, at about $60 per kWh.

Recommendations

- Renewables + storage projects: A good way to fast track manufacture and deployment of storage technologies is to incentivize all subsequent solar and wind projects to have a 10%–20% storage component. Currently solar + storage for load shifting (4 hours using Li-ion) costs `11.12 per unit.[10] With acceptance of storage technologies by lending institutions and various stakeholders can further bring this cost down making storage + solar a catchy business case.
- Need for light-handed policy and regulatory approach: Considering this dynamic, versatile, and emerging segment coupled with our current level of learning, underscores the need for a light-handed policy and regulatory approach for now. This would allow fine tuning of policy approaches based on learning from initial projects and would avoid the danger of long-term lock in. This is especially true given the lack of demonstrable projects at scale in India coupled with perceived uncertainties in applications of the technology, especially its life and performance in Indian conditions.
- Improvising existing regulatory framework: Although, the Central Electricity Authority (CEA) recently came out with a draft amendment to the *Technical Standards for Connectivity of the Distributed Generation Resources, Regulations (2013)* which addressed the issues pertaining to the standards for charging station and a person connected or seeking connectivity to the electricity system, the IEGC (Indian Electricity Grid Code) to be amended to include energy storage integration with RE. The Bureau of Indian Standards (BIS) to formalize standards for safety and reliability of energy storage batteries.
- The Electricity Act can specifically define 'energy storage' and associated mechanisms.
- India needs to adopt proactive approach and timely develop an ecosystem for secondary market (for used batteries), and re-use of rare-earth materials (case for Li-ion batteries) through recycling mechanism could be envisaged, in order to reduce in cost in medium and long-term, and to reduce dependency on lithium/ rare-earth materials import. The appropriate regulations concerning end-of-the-life disposal for batteries can address these concerns. Central and state pollution control boards along with regulators can take this responsibility.
- R&D initiatives: Supporting research and development (R&D) activities by encouraging establishment of energy storage testing labs and associated facilities to set safety protocols and standards. It can be done by creating a unified platform for all stakeholders or setting up a nodal agency, specifically for energy storage technologies.

Conclusion

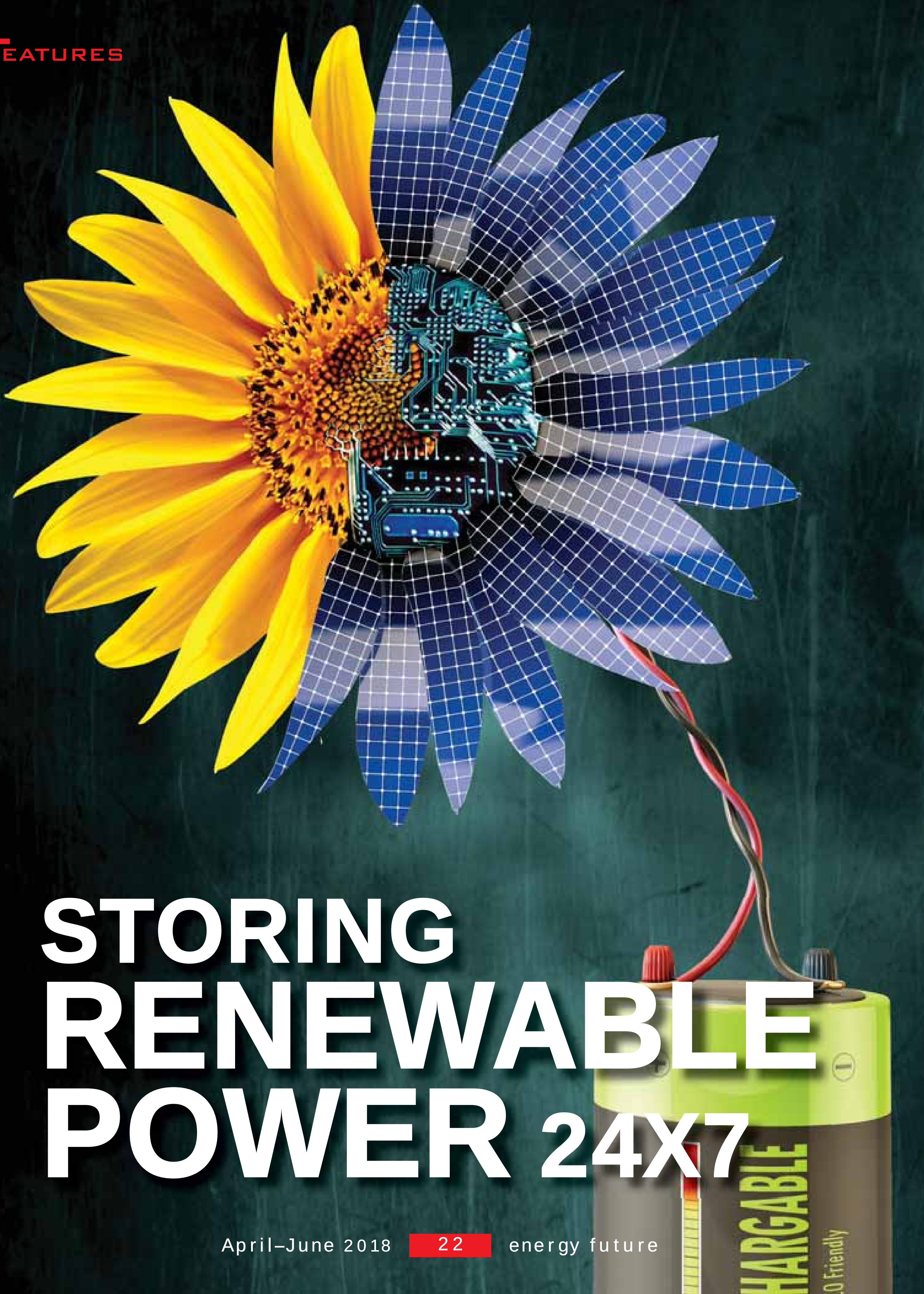
Energy storage technologies possess significant potential to help the on-going energy transition by facilitating effective integration of renewable energy, decarbonizing key energy sectors and giving more control of our energy usage. The rapidly falling costs and improving technical capabilities of energy storage systems, along with growing industry expertise, will quickly open new markets and cost effective applications for energy storage. So far, the developments in the industry have shown that the specific trends and dynamics in energy storage markets around the world vary widely depending on the specifics of each market, the applications that storage systems will provide, and the types of technologies best suited to them. Although, there are a number of barriers to energy storage market growth that must be overcome, energy storage will play an increasingly important role in the development of many emerging market countries over the coming decade.

Further Reading

1. IRENA report on Electricity Storage and Renewables: Costs and Markets to 2030
2. Energy Storage World Market Report by Azure International
3. Global Energy Storage Market Overview and Regional Summary by Energy Storage Council
4. World Energy Resources E-Storage, 2016, World Energy Council

Rashi Singh is Research Associate, Electricity & Fuels Division, TERI, New Delhi

[10] As per TERI assessment



STORING RENEWABLE POWER 24X7

Save something for the rainy days is an age-old adage which also seems to be relevant for solar PV technology usage. However, it is with a key difference that freely available solar energy available during the day is to be stored for a night time use. In simple words, solar radiation on its conversion into useful electricity via a solar cell must depend on some form of storage or the other. It is also for an added reason that rainy days at times puts a pressing need for designing a higher energy storage capacity than required. This use of solar technology is usually referred to as an off-grid use in common parlance. However, today the concept of energy storage is being mooted even for on-grid solar PV use, although for totally different reasons. Prima facie, such storage dependence is a fairly recent development and in this light, **Dr Suneel Deambi** discusses the reasons behind the changed scenario and the way forward.

Photovoltaic (PV) technology is quite capable of meeting energy needs in the milliwatt to megawatt capacity range. The game changer for the large-scale PV grid connected power generation came in terms of the Jawaharlal Nehru National Solar Mission or simply JNNSM. Today, about 20 GW of such capacity has been achieved via favourable policy and regulatory mechanisms, financial and fiscal incentives together with an enthusiastic stakeholder involvement. The fact remains that solar water pumping application was often seen as a preferred use mainly for the reason of not being dependent on energy storage. The early days of solar grid power usually witnessed the emergence of plant capacities between 1–5 MWp. That is no longer the case today as the individual plant capacity has migrated to 500 MW for the niche application of solar park and even higher, that is, 750 MW for ultra-mega power projects across the country.

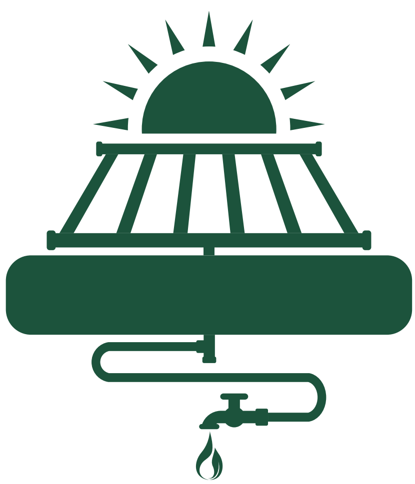
The Rationale to Store Energy

Solar energy is an intermittent source of energy with its availability varying throughout the day. Even a passing cloud formation can reduce the incident radiation levels along with other atmospheric variances during the day. This intermittency poses its own set of problems especially when evacuating the solar power to the locally available grid. Another issue is the highly ambitious target of 175,000 MW equivalent renewable power capacity to be realized by 2022. Herein, a technical issue can be seen in terms of the preparedness of the available grid power infrastructure to absorb such a large power capacity of a variable nature. Also, the PV power plant design is woven in such a manner that solar power system must shut up in case of any unforeseen grid power failure. In practice, solar power will continue to be generated during the same time but without reaching the available grid power lines. Simply put, it means loss of solar power generation even though for a small duration only.

There is a school of thought, even though a selective one, that solar power capacity is more useful when not converted to AC form via a high efficiency inverter. In simple technical terms, such a DC to AC conversion often results in a loss of power. One more reason advanced for the purpose is that solar power when converted to AC power needs voltage upgrade prior to being interfaced with the available grid. Let us now take a brief look at the contemporary options available today for energy storage in the following section.

Choosing energy storage traditionally

The concept of energy storage dates back to many years. Perhaps the most mature of all the energy storage technologies is pumped hydropower. This storage medium being techno-economically well proven is widely represented, accounting for more



than 90% of the storage. In sharp contrast, battery storage happens to be an emerging market development, especially for the large capacity power systems. A few more emerging energy storage technologies are listed as follows:

» Flywheels
» Adiabatic compressed air energy storage
» Power to gas
» Super capacitors

It is also possible to store electricity in a thermal form via the boilers, heat pumps, and ice or chilled water. Interestingly, thermal storage can well be integrated with combined heat and power production with clearly held advantage of being more economical than other forms of storage.

Way to understand the battery technology

Simply put, batteries cannot exactly be defined as a new technology. Their origin is credited to the Italian physicist, Alessandro Volta who originally invented the battery as early as 1799.

Perhaps the most mature of all technologies, that is, lead-acid batteries provided electricity at night time to the residents in New York in 1800s as per the report of Electric Power Research Institute (EPRI). In this process, cathode (positive part) is separated from the anode (the negative part) by a porous separator with an ion movement allowed between the two charges through an electrolyte. The chemical reaction creates current and voltage for powering a designated load. Further use of battery storage in the power sector can be made possible in several ways over the multiple time period. These may typically range from seconds to a few hours. The key service areas served by energy storage in broader terms are enumerated as follows:

» bulk energy
» ancillary services
» transmission infrastructure
» distribution infrastructure
» customer management services

Battery storage is quite capable of meeting the above indicated services even though with differing levels of satisfaction.

Reconstruction of the first battery invented by Alessandro Volta

India's Energy Storage Scenario

India is committed to achieving a sizeable renewable capacity addition of 175,000 MW by 2021–22. It is essentially constituted of variable renewable energy (RE) generation of 100,000 MW of solar power alongside 60,000 MW of equally promising wind power. Simultaneously though, the prices of solar power have made a dramatic turnaround from about `17 per unit under the regulated tariff by the Central Electricity Regulatory Commission (CERC) in 2010 to about `2.50 per unit at present. This is a direct outcome of the competitive bidding process, drawing participation of many players mainly the EPC (engineering, procurement, construction) companies. Likewise, the regulated tariff of wind power has come down appreciably from more than `4 per unit (in accordance with the wind zone under consideration by CERC/state electricity regulatory companies [SERCs] to around `2.60 per unit as emerging via auctions. However, few financial implications exist in

states where such variable generation is being established. This concerns the requirement of ensuring standby capacity when the wind and solar power goes below a certain limit.

Energy storage in the apital

The Jawaharlal Nehru National Solar Mission (JNNSM), successfully implemented till date, may pave the way forward for the possible start of National Energy Storage Mission with even wider gains in sight. In 2017, the Power Grid Corporation of India Ltd (PGCIL) utilized advanced lead acid and lithium-ion batteries for grid support services in a successful mode of novel project demonstration. Thus, it catalysed the next wave of adoption of grid-scale storage initiatives in the country. The construction has finally taken off on India's largest energy storage project (10 MW) which may drive another wave of utility scale projects. Significantly, the launch of this mega storage facility is a milestone in modernizing country's power system besides improving the grid efficiency. As per the Tata Power Delhi Distribution Ltd (TPDDL), this unique system in India will lend a huge impetus to opening of storage systems as a new business opportunity. The underlying rationale is to address the following few challenges hitherto encountered in the country's power system:

» peak load management
» system flexibility
» frequency regulation
» reliability on the network

AES India, a subsidiary of US-based AES

Corporation, and Mitsubishi Corp are the two big companies involved in this new generation project. These two companies will own the Advancion Storage Solution being supplied by Fluence—an energy storage technology and services company owned by Siemens and AES. The project is being set up in North Delhi (Rohini) at a sub-station operated by TPDDL and expected to be completed shortly. This 10 MW energy storage solution will enable better peak load management besides offering twin advantages of system flexibility and system reliability for more than 7 million residents in Delhi. As per the available market estimates, India has already attained 1.5 GWh of storage capacity over the last three years. The country has recently embarked on a major development initiative targeting the deployment of around 40 lakh electric vehicles. In fact, a few chosen Indian companies, such as Exicom, Delta, and ACME, have set up more than 1 GWh of annual production capacity for lithium-ion battery pack manufacturing.

Energy Storage: The Global Perspective

Energy storage is a fast-emerging technology option in keeping with stable power requirement. As per the available estimates, more energy storage is now being added worldwide. However, dependence on policy support is leading to irregular growth. Worldwide, installations of energy storage touched about 1.17 GW during 2017, indicating a jump of 4.6% over the corresponding figure for 2016. Equally true, 2016 registered a growth of 61% in comparison to the figures for 2015, thus clearly implying the slowing down of energy storage market in the span of last 12 months. There is a strong expectation of witnessing a six-fold growth in this sector by 2030. Today, solar and wind power despite being intermittent renewable electricity generation sources are being added to the global grids. The fact remains that storage technology continues to be dependent on subsidy and, often irregular, government support in several countries around the world.

The average price of a battery pack is still quite expensive for many potential distribution consumers despite a drop in the battery cost by about 24% to $209 per kWh in 2017. The fact that battery prices must nosedive further in a bid to sail through to the bigger markets is quite evident. In terms of country perspectives, South Korea leads the group with installation of energy storage capacity of about 406 MW in 2017. This has mainly been possible due to availability of some incentives, such as discounts on electricity rates to adopt such systems. In some countries, a debate on the ways and means to adopt and support storage technology is underway. The cumulative storage capacity added was about 522 MW within North America and South America in 2016, a drop of 3% over the 2016 figure. Likewise, attempts were made to take recourse to new routes towards early commercialization of the battery technology. Importantly, a Swedish-based company is embarking on a major manufacturing initiative to produce about 32 GWh of battery cell capacity by 2030.

Conclusion

India has realized a solar PV grid connected power generation capacity of around 20 GW till date, mainly under the ambit of the National Solar Mission. The larger purpose was to quickly evacuate the power thus generated into the locally available grid rather than storing it in a vast battery bank. Of late, in order to reduce intermittence as well as improve its integration into the grid, the country is toying with a larger idea of building energy storage for the RE projects, more so for solar PV projects. It may be a well-timed move to begin experimenting with the relative merits and demerits of energy storage solutions, particularly for the renewable energy-based plants. A beginning of sorts should be made with the setting up of a few demonstration projects. Unfortunately, however, several tenders involving battery storage for the RE projects stand cancelled, thus sending a fluctuating signal to the prospective developers of such projects. One such widely reported 28-MWh project was that of Mahindra Susten's storage-cum-solar project for Andaman and Nicobar Islands which was scrapped despite the company having won a bid (`2,890 million) for the Neyveli Lignite Corporation (NYC) in 2017. Incidentally, the island region meets all its existing power demand through diesel-run power generators and this project was to have a 20 MW solar capacity supported by 28-MWh of battery storage. Earlier, the National Thermal Power Corporation (NTPC) had also scrapped a storage-linked project even before it was awarded.

Agreeably, India's energy storage industry is not on the same page as the global players. The moot question is that an evolutionary phase in energy storage solutions must begin sooner than later wherein energy storage products and technologies will begin to look more attractive from the pricing side. The need of the hour is to earmark some budgetary outlay for the specified purpose of pushing up the energy technology frontiers from a variety of end-use considerations.

A unique attribute of storage technologies is their across the board demand for meeting power demands in the milliwatt to megawatt range. After all, energy storage seems to be extremely vital for grid stability, integration of renewables, and in no less measure for the electric vehicles or simply the EVs. With the advent of modern day gadgets such as mobiles and laptops, etc., the die has already been cast for the large-scale entry of lithium-ion batteries. This is going to pose a good challenge to the lead-acid battery market with a sizable presence in India. So, let us think of storing the big power too with several advantages in sight for sure. EF

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ENERGY STORAGE: KEY TO A RENEWABLE ENERGY FUTURE

In 2016, over 150 GW[1] solar and wind energy installations materialized at the global level, thanks to the vibrancy in markets, such as India and China. However, the supporting grid systems have been slow to catch up, especially for renewable energy, an infirm and inconsistent source of power.

With the cleantech sector assuming centerstage and massive investments in technology, this sector will only become bigger, especially in the wake of the Sustainable Development Goals 2030. The ambitious targets envision clean and affordable energy deployments which can have a transformative effect on people's lives the world over. However, since the sun does not shine in the night or the wind blows has spurts, it is only pertinent to store the energy generated to best utilize the power during times of need. While utilities struggle to balance the demand and supply, energy storage is being seen as a potent solution for solving the intermittent renewable power generation.

The spike in energy demand can be attributed both to the rapid development of countries across the world along with supersized penetration of technologies in the lives of people. From gadgets to appliances or even future mobility expected to be driven completely through electricity or newer technologies, companies are fast installing power plants to meet the ever-growing energy demand. Additionally, the increasing pollution that led to serious commitments under the Paris Agreement by most countries is leading to a surge in clean energy installations all over the world. In this article, **Viraj Desai** takes a closer look at the significance of energy storage in India and the world, the recent industry trends, and the technologies available in the domain.

Necessity of Energy Storage

First and foremost, energy storage is already making economic sense in certain cases. This might be ignored due to the semblance of subsidies and immeasurable economic rationales, such as resilience and insurance against outages.

Second, there is a need to identify customers who can start paying for energy storage technologies to provide a substantive thrust to the nascent market. Third, storage providers need to look at innovative design mechanisms, be it lithium-ion, lead-acid, flow-cell or some other technology, which may provide the best value. Such a strategy may be a little costly but will be sustainable over the long run. The vital part of all these is that large-scale deployment will overturn the usual business for a lot of established electricity markets in existence over a century or more. Yet, it is necessary to realize that the future beckons energy storage to ensure sustainability.

The Future Belongs to Lithium

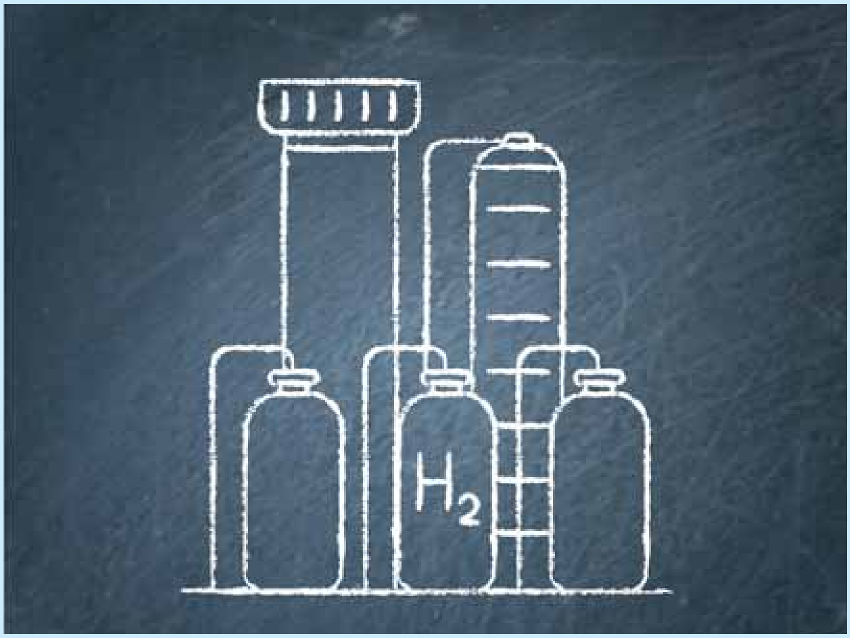
Lithium-ion batteries, whose usage was started by Sony[2] back in 1991, are now being seen as the answer for energy storage in a large part of the world. From distributed energy storage to mobility, these batteries have already started acquiring significant importance. The likes of LG, Tesla, and BYD advocate technology as the best solution for global electrical energy storage needs. In fact, it is anticipated that lithium mines will be the new oil in the near future. However, the downside of lithium battery for storage is the relatively shorter battery life if charged and being discharged on a daily basis, in addition to the high end-of-life recycling costs.

It is yet to be determined how utility-scale lithium battery usage is justified for health and safety in addition to the longevity subjected to varied weather conditions. It is imperative to provide incentives so that storage systems are ensured in the core transmission and distribution networks.

Lithium-ion batteries may be the future but vanadium flow-batteries may fit into applications where many hours of storage are required.

Other emerging technologies for storage include flow batteries, zinc air, sodium-sulphur, silver-zinc, and nickel-zinc driven by research being conducted by universities, such as Stanford, California Berkeley, MIT, and institutions in South Korea, Japan, China, and Germany. Markets will gradually

evolve and reliable batteries are sure to dominate the market.



Revved up Global Energy Storage

The USA, one of the largest countries with high energy consumption, is already taking the lead to move towards energy storage with 140 different state-level policies[3] and regulations regarding utility energy storage—either pending for approval or already in place. States, such as California, New York, Nevada, and Massachusetts have set ambitious energy storage targets. These factors have all spurred the growth of energy storage capacity: In fact, there was six times more storage capacity (excluding pumped-storage hydropower) in 2017 than in 2007.

Some other examples of the USA taking a lead in energy storage solutions include the Punkin Center, Arizona, where local utilities are installing 8 MW hours of battery storage, which would make them use 20 new miles of transmission lines. On the other hand, Vermont[4], the utility Green Mountain Power built a solar farm and utility-scale battery microgrid that can save the utility roughly $200,000 per year. SolarCity, the largest residential PV installer in US, has already started installing storage systems dependent on lithium-ion batteries, powered by the electric carmaker Tesla. Both organizations work under the aegis of Elon Musk, the world-famous entrepreneur, who is hoping to offer solutions to enable residential customers to utilize time-of-use rates and photovoltaic (PV) system interaction. The company is already making a 200 kW project for storing energy from the rooftop at Tesla's factory in Fremont, to offset millions of dollars. Tesla, which is making a gargantuan $5 billion lithium-ion battery factory in Nevada, the largest in the world, is expected to topple the established and existing electricity systems across the US.

One of the trendsetters in Europe which will require 3 GW to 30 GW over the next 4–6 years is Germany. This has been confirmed by Fraunhofer[5], Europe's largest application-oriented research organization, which predicts that 13 GW to 50 GW of energy storage would be needed by 2030. German organizations, such as Siemens and AES, have set up an energy storage platform known as Fluence looking at the future scope. Since storage lasts only for few hours, researchers in Siemens are focussing on converting electricity into energy like hydrogen and chemicals. One of the earliest initiatives is the pilot project for hydrogen generation, Mainz Energy Farm, which currently generates 6 MW, perhaps the largest plant anywhere in the world.[6] This can produce enough hydrogen for 2,000 fuel-cell cars.

The United Kingdom (UK) is expected to deploy over 9,000 MWh battery energy storage over the next five years as the sector continues to grow, as highlighted in the publication, *UK Battery Storage: Opportunities & Market Entry Strategies for 2018-2022*. The report suggested that the country's new battery storage projects have grown by over 240%, especially due to drivers, such as national commitment to phase out coal, falling technology costs, and wind and solar capacities of more than 30 GW.

It is expected that global storage deployments may stand between 2–4 GW[7] in 2018, with South Korea emerging as the single largest market.

VC Space Heating up

According to Mercom's (a consulting and communications group which has offices in the US and India) latest report on venture capital (VC) funding and merger and acquisition, activity in the battery storage, energy efficiency, and smart grid spaces has shot up, demonstrating the interest of the investor community.[8] From just 38 deals in 2016 worth $365 million, investments doubled to $714 million in 2017 with just 30 deals in the battery energy storage companies. While a large part of this was the funding to Microvast Power Systems, a Chinese company manufacturing lithium-ion batteries for electric vehicles (EVs), leading to raising $400 million in the first half of 2017. Other than that, UK's Battery Energy Storage Solutions or BESS, raised $66 million. The other startups that raised funding included Forsee Power, a French company formerly known as Dow Kokam France with $65 million; Advanced Microgrid Solutions, a large US energy storage firm with $34 million raised, and also a flow battery maker Primus Power, raising $32 million in VC investment the same year.

Industry Potential

Last year, a report by the Bloomberg New Energy Finance[9] forecasted the global energy storage market to surge by six times to 2030, which may see investments of $103 billion in the domain.

According to many industry sources, the maximum potential for energy storage will be surrounding solar energy followed by wind energy. It is estimated that hybrid solar wind energy storage market will be worth $1.5 billion by 2024, according to Global Market Insights.

IHS, an esteemed energy consultancy, has assessed the energy storage market to grow to over 40 GW by 2022. According to McKinsey, the economic impact of energy storage would be over $90 billion a year by 2025 and may be $635 billion provided the electric vehicle market kicks off. Though it is a drop in the ocean of the $6 trillion global energy market, it will bring many opportunities for both conventional and non-conventional players along with original equipment manufacturers (OEMs).

Manufacturing on the rise

Currently, battery production is concentrated in Japan and South Korea, with the production surging in China. Chinese lithium-ion giant Contemporary Amperex Technology Co Ltd (CATL) intends to focus on production of 50 GWh storage annually by 2020, which suffices to power 40,000 EVs for travelling 100 km. Global bigwigs like Tesla are finding it difficult to find a foot in the Chinese market due to protectionist policies. Chinese companies are also making investment in lithium mines both in Argentina and Chile.

Chinese companies have already planned factories setting up a formidable capacity of more than 120 GWh a year by 2021, according to a report by Bloomberg Intelligence.[10] The prices of lithium-ion batteries have plummeted from $10,000 per kilowatt-hour in early 1990s to about $100 per kilowatt-hour in 2018 and this is leading to economies of scale for the industry to flourish. However, there is a thought that flow cells might be more economical than lithium-ion cells and may become cheaper in the next few years.

India's Energy Storage Market

India, a country fast expanding its renewable footprint every year, is at a basic level on energy storage solutions (ESSs), with certain available facilities being very expensive. Another area where the country is witnessing tremendous demand is the data, leading to surge in telecom towers and backup renewable options. Leading electronic company Panasonic recently started offering li-ion-based ESSs that can be used as a backup to reduce both diesel consumption and mitigate environmental hazards. Since data centres will be critical, reliability of storage, and organization and management (O&M) is a necessity for telecom organizations. This is why companies like Panasonic are delivering reliable solutions that have the capacity to reduce energy consumption and transform the energy landscape. In addition, the Japanese giant believes that the market for electric vehicles will grow every year with the rise in environmental awareness.

The Indian Energy Storage Alliance[11] stated that India has the potential of 15–20 GW storage by 2020. Recently, the state-run coal mining and power firm, NLC India auctioned 20 MW solar PV project in tandem with 28 MWh of energy storage capacity in the Andaman and Nicobar Islands. Mahindra Solar, a part of the conglomerate, Mahindra Group, won the auction indicating the immense interest of players in the relatively nascent sector. The Ministry of New and Renewable Energy, Government of India, and state-run Power Grid Corporation, intend to open up bids for grid-scale energy deployment. The organization feels that large-scale adoption of energy storage may attract investments of over $3 billion by 2020, with 24 giga factories being set up.

The Indian company, Energy Efficiency Services Ltd which is working on procuring electric vehicles for government fleet, tied up last year with Leclanche SA, Swiss maker of lithium-ion storage batteries, for on-grid stabilization in Canada. The company is investing $120 million and aims to establish battery storage

infrastructure manufacturing in North America. According to the company's chief managing director, India will need storage infrastructure soon at some point and the collaboration aims to test the waters. Another Indian company, Infrastructure Leasing and Financial Services (IL&FS) Ltd recently tied up with Canadian clean technology company, Ecamion Inc, a turnkey solutions provider for community energy storage, in order to explore the energy storage business.

India has envisaged a major overhaul of its automobile fleet by completely turning to electric vehicles by 2030, highlighted in the National Electric Mobility Mission Plan (NEMMP). To support the stupendous growth driving renewables and spurring EVs in India, the country has identified storage technologies as extremely pertinent. With this aim, the *India Energy Storage Mission*[12], a report from NITI Aayog, the premier thinktank and Rocky Mountain Institute, suggested that 100% domestic manufacturing of batteries will entail 3,500 GWh of batteries at cost of `20 lakh crore from 2017–2030.

NEMMP suggests that the country may become a leader in battery manufacturing with a domestic market of $300 billion by 2030, making up two-fifths of global EV battery demand. To spur this, the government may need to lower taxes for incentivizing solar energy storage manufacturers.

Some of the leading organizations have already expressed a desire to move rapidly in the energy storage business. Indian Oil Corporation, the nation's largest fuel retailer, is one such company planning a foray with an improved version of lead-acid battery for industrial applications as well as low-cost mobility. Recently, AES India, a subsidiary of US-based AES Corporation, and Mitsubishi, started construction of a 10 MW utility-scale energy storage system, India's first, which would serve the private power distribution company, Tata Power.

One of the largest battery manufacturers in the country, Amara Raja, tied-up with Galla Family and Johnson Controls, to explore avenues in the Indian battery storage industry.

India's commerce minister, Shri Suresh Prabhu, had stated that energy may change the dynamics of the industry globally and felt that there is a need to conduct more research and development (R&D) for India, which has embarked on setting up 175 GW[13] solar and wind power by 2022. In fact, the Karnataka state government, which is aggressively pushing on the electrification agenda as it brought out a policy recently, highlighted its vision on energy storage. Some of the major companies working in storage in India include Power All, Mahindra, Exicom (which aims to have storage capability of over 1 GWh by 2019), and ACME. Additionally, Kest Technology, with flywheel storage capabilities and PuNeng Energy with emerging flow battery technology are exploring newer possibilities in the market. In fact, even the startup market in India is gearing up for energy storage systems and some action is already visible. The Indian energy storage startup ION Energy acquired French battery management company Freemens SAS this year, which would lead to ION investing in growing the portfolio of customers in India, US, and other parts of EU. EF

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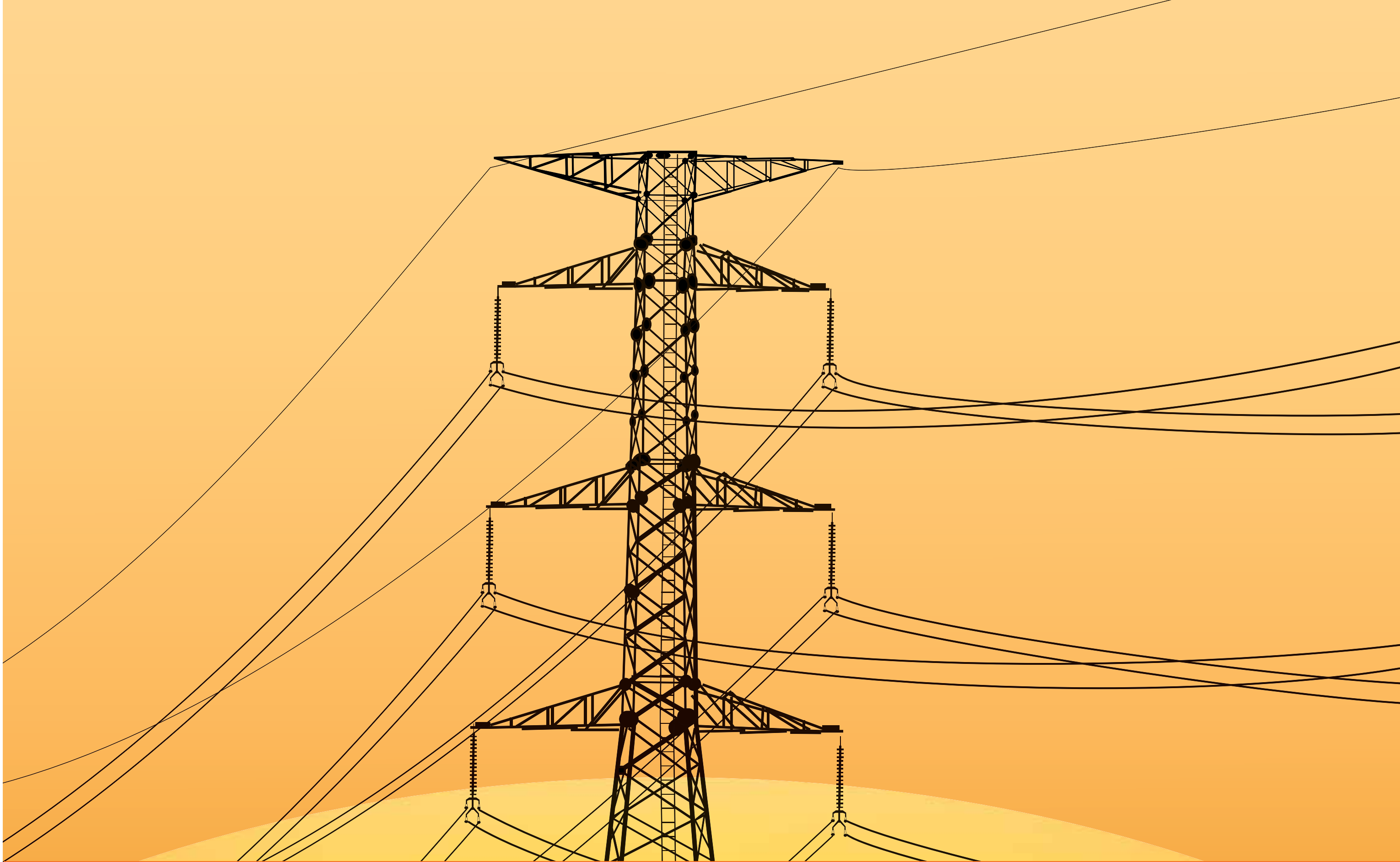
Endnotes

1 http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf
2 http://jes.ecsdl.org/content/164/1/A5019.full
3 https://www.windpowerengineering.com/environmental/progress-energy-storage-can-expedite-shift-clean-energy/
4 https://pv-magazine-usa.com/2016/11/23/solarstorage-cuts-vermont-utility-grid-charge-by-200000/
5 https://www.isi.fraunhofer.de/en/presse/2017/presseinfo-29-2017-hochenergie-batterien-2030.html
6 http://hydrogenvalley.dk/kick-off-worlds-largest-electrolysis-system-in-deutschland/
7 https://www.pv-magazine.com/2018/02/15/global-storage-growth-of-4-6-in-2017-reflects-patchy-state-of-sector-finds-bnef/
8 http://mercomcapital.com/battery-storage-smart-grid-and-efficiency-companies-raise-over-$1-billion-in-vc-funding-in-1h-2017-reports mercom-capital-group
9 https://about.bnef.com/blog/global-storage-market-double-six-times-2030/
10 https://www.pv-magazine.com/2017/07/31/study-finds-that-storage-prices-are-falling-faster-than-pv-and-wind-technologies/
11 http://www.thehindu.com/sci-tech/energy-and-environment/draft-mission-to-kick-start-renewable-energy-storage/article23713031.ece
12 http://niti.gov.in/writereaddata/files/document_publication/India-Energy-Storage-Mission.pdf
13 https://mnre.gov.in/file-manager/annual-report/2016-2017/EN/pdf/1.pdf

INTERNATIONAL COOPERATION TO BOOST UPTAKE OF CLEAN ENERGY IN SOUTH ASIA



Unlocking Nepal's substantial hydropower potential is a project decades in the making with huge potential benefit to Nepal and India. Nepal now has a unique opportunity to strengthen its power sector through a historic partnership with the Millennium Challenge Corporation (MCC), a US government agency focussed on reducing poverty through economic growth. This opportunity dovetails with the priorities of Nepal's new government, which includes infrastructure development, energy, and prioritizing increased energy production to help eliminate Nepal's recurring blackouts. With the MCC investment also comes business, procurement, and investment opportunities for firms, including those in Nepal, India, and beyond. **Jonathan A Brooks**, through this article, presents the rationale behind the partnership and the way forward.

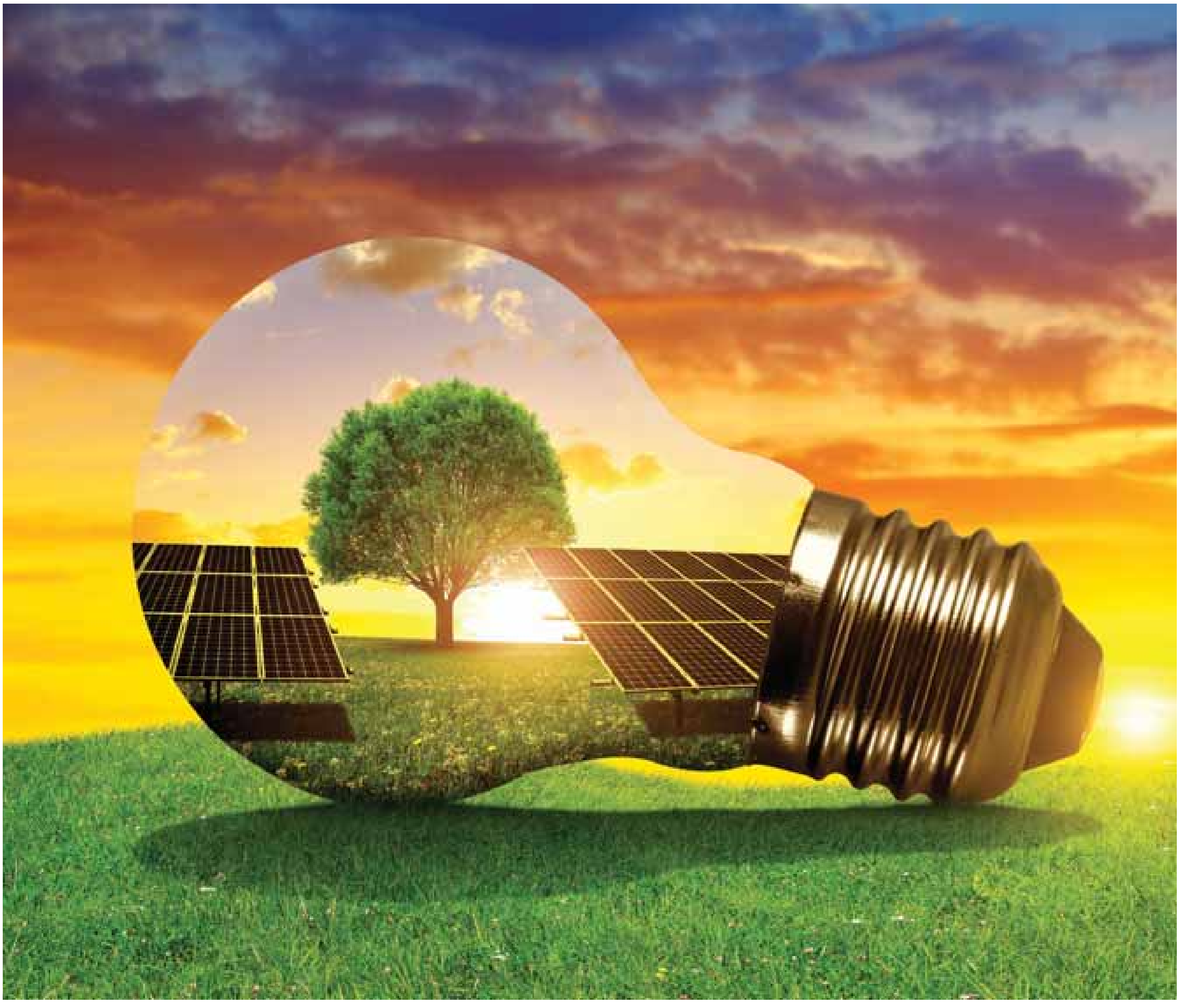
On September 14, 2017, the Millennium Challenge Corporation (MCC) signed its first investment in South Asia, a $500 million grant to Nepal, which will be matched by an additional $130 million from the Government of Nepal. Once the compact enters into force, the Nepal Government will have five years — and five years only—to complete this investment.

Through the compact, MCC will invest in core electricity transmission assets, complementing an existing pipeline of new generation projects to help move electricity both within and across Nepal's borders in order to meet domestic demand in the near term and allow surplus electricity exports in the long term. Specifically, the investment will build out 300 km of Nepal's 400 kV East-West transmission backbone and complete the Nepal portion of the second Nepal–India cross-border line from Butwal in Nepal to Gorakhpur in India. This cross-border line is intended to carry power from planned generation plants to demand centers and ensure connections between the Nepali and Indian power systems to optimize seasonal power generation. MCC therefore decided to focus its power sector projects in Nepal on domestic and cross-border transmission. The cross-border transmission investment was considered particularly important to support successful implementation of Power Purchase Agreements (PPAs) with Independent Power Producers (IPPs) by ensuring there is export potential during the rainy season.

With complementary investments already planned in downstream distribution, MCC is confident its projects will result in increased availability of electricity for consumers, addressing one of Nepal's binding constraints to growth and further fueling India's growth. Reaching an agreement to finance and operate the cross-border line has been set as a condition that must be met in order for the MCC Nepal Compact to enter into force.

For both Nepal and India, the potential economic benefits of the MCC Compact are significant. For the first time, majority of Nepal would have consistent access to electricity, reducing household costs, and the stress of constant outages. Businesses will feel direct impacts—reducing their dependence on generators and start-up costs, and removing a major cause of production uncertainty. With an addition of a crucial cross-border line at Butwal–Gorakhpur, both countries will be able to import and export additional energy to support economic growth on both sides of the border. MCC's investment also contributes to regional energy connectivity to serve the growing power needs of South Asia generally and India specifically. In a 2017 report, BP Energy Outlook forecast Indian energy consumption to grow at 4.2% per year by 2035, faster than all other major world economies. In hydropower specifically, India is projected to see a 97% increase in demand. As India

Representatives from the Governments of Nepal and the United States at the signing ceremony for the MCC Compact - September 2017



expands power trade with Bhutan and Bangladesh, it now has an opportunity to create momentum for more robust power trade with Nepal. While in the short term, this trade will largely focus on Indian exports to the Nepali market, with the right investments and regulations, Nepal in the long-term could make surplus capacity available to meet Indian needs.

In addition to finalizing the modalities for operationalizing the Butwal–Gorakhpur transmission line, the Nepali government must also complete all necessary land acquisition, site access, and forest management for project areas; designate the electricity transmission project as a National Priority Project to expedite decision making and garner essential political support; and ratify the compact.

As the Government of Nepal works to fulfill these conditions, MCC's first procurement offers are beginning to take shape, providing concrete business opportunities for companies in Nepal, India, and the region. In addition to ongoing procurements for human resources recruitment; banking services; and technical design, supervision, and environmental management services , future procurements will be announced via the MCC website at <www.mcc.gov> as well as through local newspapers, DG market (www.dgmarket.com) and UN Development Business (www.devbusiness.com). The Government of Nepal has also created social media pages for partnership opportunities with local firms via LinkedIn (https://www.linkedin.com/groups/10342965) and Facebook (https://www.facebook.com/groups/Millenniumchallenge/).

MCC is excited about this new and historic partnership with Nepal. Together, we will work with critical stakeholders in the region to strengthen the power sector, increase prosperity, and stimulate economic growth. EF

Jonathan A Brooks, Deputy Vice President, Europe, Asia, Pacific, and Latin America, Millennium Challenge Corporation, USA

TRENDS IN PROTON EXCHANGE MEMBRANE FUEL CELL VEHICLES

Through this article, **Er. Bandi Mallikarjuna Reddy**, **Dr Paulson Samuel,** and **Dr Narapureddy Siva Mohan Reddy,** reiterate how the government policies in India have helped in promoting clean transport and development of vehicles that use proton exchange membrane fuel cells (PEMFCs). In 2004, the Banaras Hindu University (BHU) and the Ministry of New and Renewable Energy (MNRE) developed a motorcycle using a new fuel cell technology based on PEMFCs. Later in the 2010s, the Indian Space Research Organization (ISRO) and TATA jointly developed a passenger vehicle project named 'Starbus', based on PEMFC technology. The Government of India promotes various schemes and policies for the research and development carried out by major players of fuel cell systems in the country, which includes research and educational institutions and industries.

Introduction

In a current study, McKinsey & Company have estimated that India needs an economic growth of 10% to satisfy the wishes and aspirations of a population, already at 1.3 billion by 2017, and grow without polluting the environment. The government has taken steps towards the development and deployment of green energy and has extended support to the public and private players in the field of green energy, such as ISRO and TATA Corporation Ltd. Since India is still a part of the developing world, the major technical challenges in this area include identification and development of suitable fuel cell technologies for applications often unique to the developing world.

Classification of Conventional Fuel Cells

A fuel cell is the main energy source of modern electric vehicles such as those run by proton exchange membrane fuel cells (PEMFCs), which would become very common in the future due to their zero emission and other beneficial use as distributed storage when used with advanced converter and battery technologies in the smart grid apart from their use in the transportation sector. Figure 1 shows the description and operation of each class of fuel cells classified on the basis of the fuel used in the fuel reformer.

Direct Methanol Fuel Cells

The direct methanol fuel cells (DMFCs) are a relatively new type of fuel cells that resemble PEMFCs in that they utilize polymer electrolytes (sulphophynelated sulphonic). A typical solitary DMFC can supply just 0.3–0.5 V under loaded conditions. DMFCs are used to replace the batteries for cameras, scratch pad PCs, and other convenient electronic applications in the power range of 1 W to 1 kW. The internal operation is constrained by two vital processes, which bring down the framework efficiency (40%). Figure 2 shows the principle of operation of DMFCs on the basis of chemical equations.

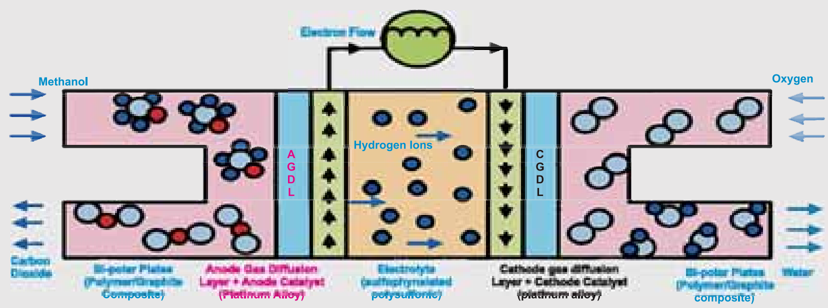


Figure 2 Portrayal of internal operation of direct methanol fuel cells

Proton Exchange Membrane Fuel Cells

A solid membrane of natural material such as polystyrene sulphonic acid is utilized as an electrolyte in PEMFCs. This fuel cell works at 40 °C–60 °C, and the low-temperature operation allows it to start quickly, which results in lesser wear on system components and, consequently, better durability. Figure 3 shows the explanation of PEMFCs on the basis of chemical equations.

Alkaline Fuel Cells

The alkaline fuel cells (AFCs) utilize 40% aqueous KOH as an electrolyte and work at temperatures around 90 °C. They are the most seasoned fuel cells, and their fuel is free of carbon dioxide. AFCs were utilized in the Apollo shuttle to facilitate the supply of both power and drinking water. Figure 4 explains the operation of AFCs on the basis of chemical equations.

Phosphorous Acid Fuel Cell

Invented in the 1980s, a phosphorous acid fuel cell (PAFC) consists of two electrodes of porous conducting

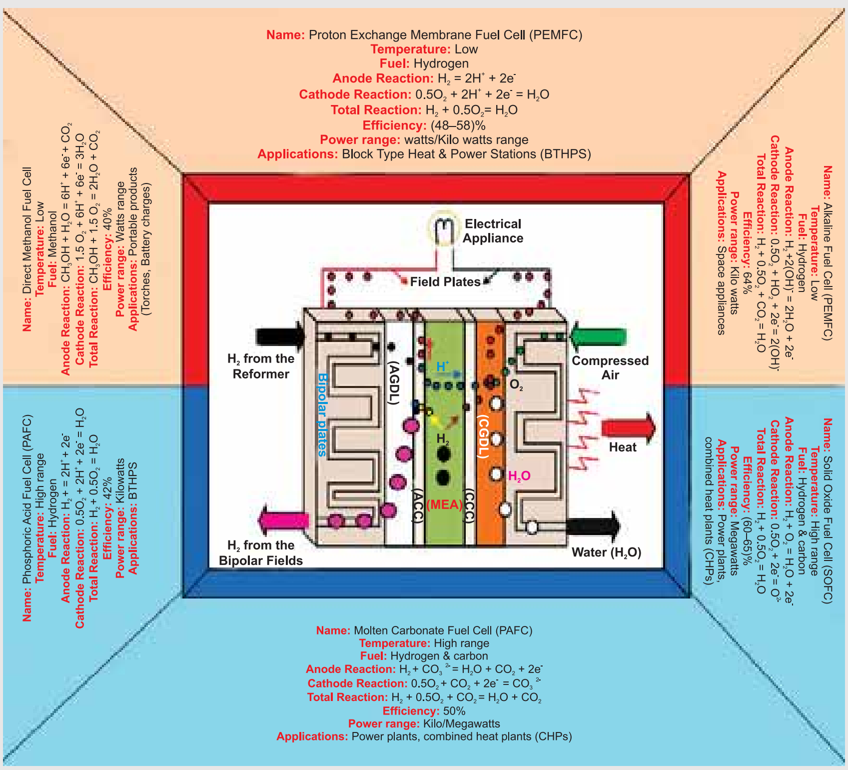


Figure 1 Description of operation of fuel cells with the representation of characteristics of major fuel cell types based on the usage of membrane electrode assembly (MEA)

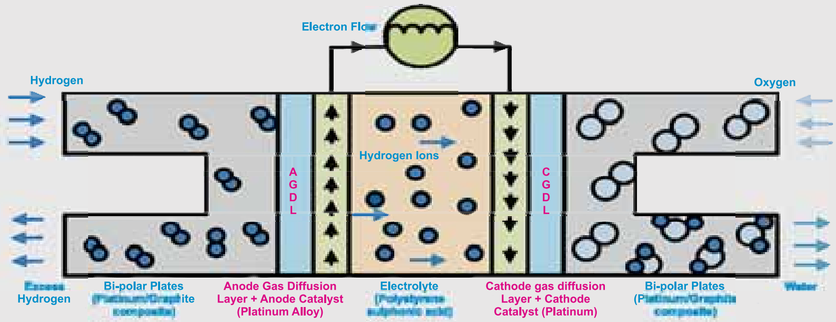


Figure 3 Portrayal of internal operation of proton exchange membrane fuel cells

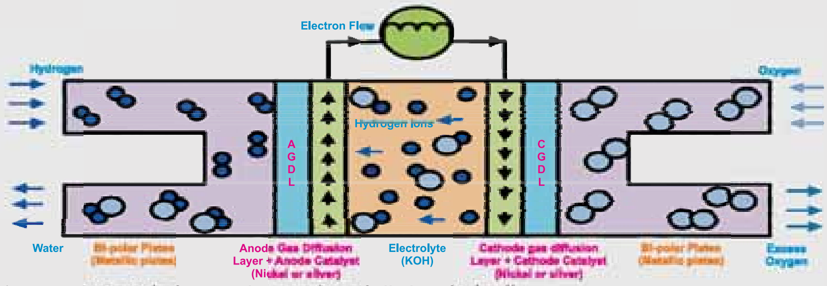


Figure 4 Portrayal of internal operation of alkaline fuel cell

material (usually nickel) to receive charge, with concentrated phosphoric acid filled between them to function as an electrolyte. Platinum catalyst is added to both electrodes to increase the rate of the reaction. Figure 5 explains a PAFC on

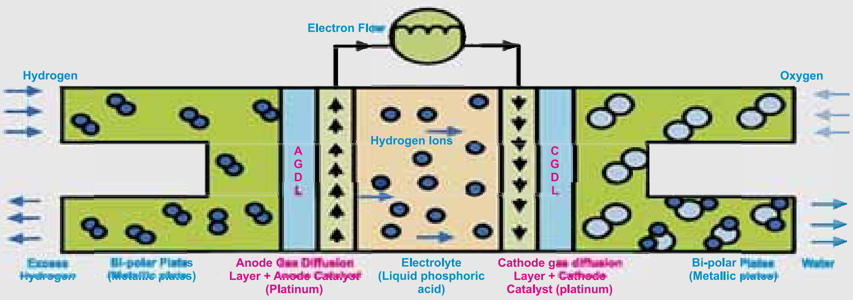


Figure 5 Portrayal of internal operation of phosphorous acid fuel cells

the basis of chemical equations.

Molten Carbonate Fuel Cells

The molten carbonate fuel cells (MCFCs) utilize carbonates of alkali metals in the molten state as an electrolyte. This requires cell operation over the melting point (around 600 °C–700 °C) of the separate carbonates. In view of high temperature, it does not require any catalyst. Figure 6 gives an explanation of MCFCs on the basis of chemical equations.

Solid Oxide Fuel Cells

The solid oxide fuel cells (SOFCs) utilize a hard, ceramic compound of metal (such as Ca or Zr) oxides as an electrolyte and are suitable for high-temperature conditions of around 600 °C–1000 °C. The anode is made of porous nickel, and the cathode utilizes metal oxides such as indium oxide. The exhaust heat can be reused in a combined heat power plant to further boost the overall efficiency of the plant. Figure 7 gives an explanation of SOFCs on the basis of chemical equations.

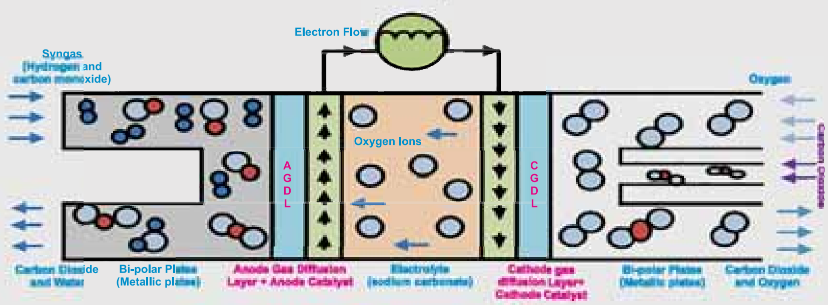


Figure 6 Portrayal of internal operation of molten carbonate fuel cells

Topologies of Drivetrains of Electric Vehicles

Drivetrains are the heart and soul of any vehicle, especially of the four-wheel category. Advances in drivetrains have played a key role in PEMFC vehicles because of the new techniques that control the acceleration and deceleration of drivetrains by using front wheel drive. Vehicle manufacturers are developing rear wheel drives and all wheel drives for the effective usage of fuel and improvement in the efficiency of fuel cell vehicles (FCVs). Figure 8 gives a comprehensive analysis of complete drivetrains for electric vehicles, which are described in the following sections.

Battery Electric Vehicles

A purely electric drive system principally replaces the internal combustion engine (ICE) and the various transmission systems with an all-electric system (power electronics and superbatteries). The practical electric vehicles still use lead-acid batteries, with the more sophisticated ones using nickel-metal hydride (Ni–MH) batteries.

Series Hybrid Electric Vehicles

A series hybrid electric vehicle (SHEV) is fundamentally an electric vehicle with an on-board battery charger. An ICE is generally run at a desired efficiency point to drive the generator and charge the on-board battery. SHEVs would run at their optimal torque and speed for saving fuel and improving the efficiency