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ENERGY FUTURE

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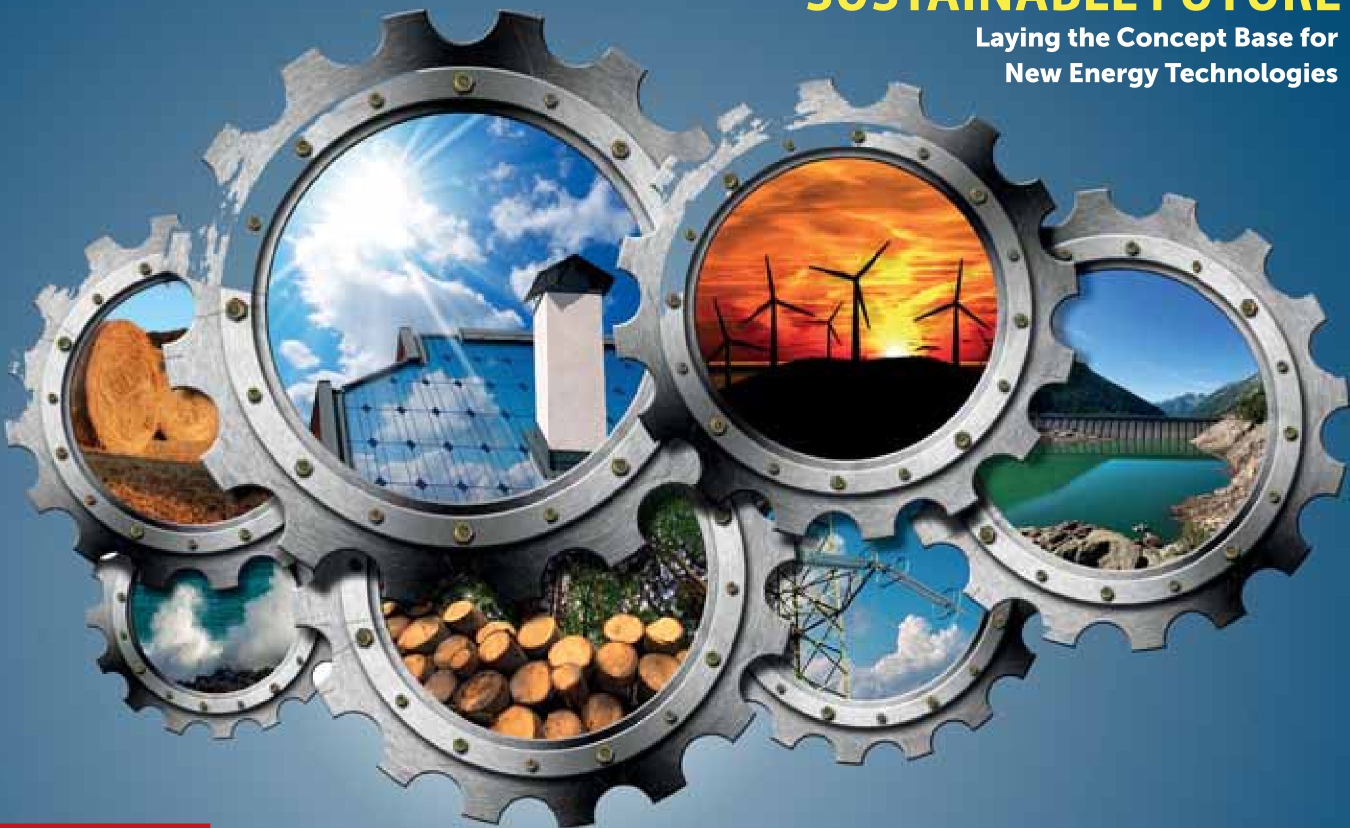
COVER STORY

INNOVATIONS FOR SUSTAINABLE FUTURE

Laying the Concept Base for New Energy Technologies



VIEW POINT

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THE CLEAN ENERGY REVOLUTION

Building Storage Capacity

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From the editor's desk...

Decarbonization of growth pathways has lately become a key concern for the governments worldwide. The reasons range from local environmental issues to energy security to global climate change to general well-being of populace. Demand side management and renewables-based energy supply are cornerstones of low-carbon strategies. Over the years, many such technologies have matured resulting in their rapid proliferation. That, however, does not inhibit further developmental research and more innovations. Ultimately, continuous innovations alone would pave the way for energy transformation, the beginning of which is already visible now. While on one hand, focus is on newer technologies and products; on the other hand, it entails novel applications, practices, and services. Indeed, the efforts are underway to clean up even fossil fuels based generation and value chain, whether through `low emissions high energy' clean-coal technologies or through post-mining processes, such as coal beneficiation. Interestingly, clean-coal technologies are being considered as interim solutions till the time renewable energy becomes competitive in a broader sense—technically and commercially.

Since the UN Climate Change Conference (COP 21) in Paris in December 2015, global collaborations are being shaped up around clean energy innovation. The major ones include `Mission Innovation' and `Breakthrough Energy'. While `Mission Innovation'—a grouping of 22 countries and the European Union—is fostering greater thrust on R&D; `Breakthrough Energy' is a coalition of global business leaders aiming to accelerate the innovation cycle by complementing public research through provisioning of private risk capital. These, and many other initiatives at different levels, indicate the importance of innovative technological solutions in helping the nations in transiting to carbonless future. Innovations that help crossing the tipping point to cleaner energy options that are reliable, convenient, and affordable. Certainly, future of energy lies in newer technologies and ingenious innovations.

Amit Kumar

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Senior Director, Social Transformation, TERI

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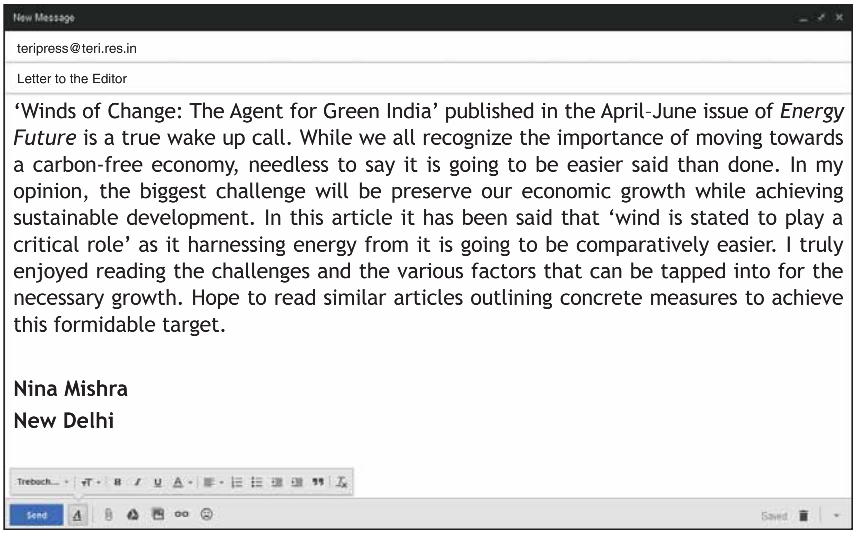
New Message

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Letter to the Editor

'Winds of Change: The Agent for Green India' published in the April-June issue of *Energy Future* is a true wake up call. While we all recognize the importance of moving towards a carbon-free economy, needless to say it is going to be easier said than done. In my opinion, the biggest challenge will be preserve our economic growth while achieving sustainable development. In this article it has been said that 'wind is stated to play a critical role' as it harnessing energy from it is going to be comparatively easier. I truly enjoyed reading the challenges and the various factors that can be tapped into for the necessary growth. Hope to read similar articles outlining concrete measures to achieve this formidable target.

Nina Mishra
New Delhi

Send

'Harnessing offshore wind energy is yet to gain momentum in the effort to achieve the necessary carbon-reduction goals. The feature article titled 'Offshore Wind Energy System' talks about the emerging trends in electricity generation in the form of non-conventional energy system. While offshore wind power is the use of wind farms constructed offshore, usually on continental shelves, it is important to study the different system parameters, software tools, grid parity, and greenhouse gas emissions from offshore wind system. In my opinion this sector has great potential given the subcontinent's extensive 7,000 km coastline. Given this, I look forward to seeing how the different challenges, such as soil-structure, are negotiated. Kudos to Energy Future for publishing such pertinent articles on wind energy.

Bhavana Shukla
Allahabad

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.

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Editor
Energy Future

Given the overwhelming needs for achieving sustainable goals, wind energy is being developed as a potent source of generating clear sustainable energy. Published in the April–June issue of Energy Future, the feature article titled 'Wind Energy: Challenges and Possible Solutions', carefully positions the challenges that this sector faces. Given the obvious advantages, wind energy systems are continuously expanding worldwide and improvements in design of turbines have led to the ready availability of wind resource. However, integrating all this power in to systematic grids is yet to be streamlined. What I appreciate most about this article is the way in which this problem has been explained along with certain supportive measures that can be adopted to compliment or guide the way in which the 60 GW-target can be achieved by 2022.

Manish Trivedi
Hyderabad

The article titled 'Biofuels: Potential of Waste Biomass to Power Movement', published in the latest issue of Energy Future, poses some of the most pertinent questions in the field of renewable energy. Living in a metropolitan city comes with its own challenges of which the stress induced by the transport sector is immense. To make matters worse, and with little wonder, this sector is poised to increase its energy demand by 60% in the not-so-distant future. In this ever-increasing energy scenario, electricity is one of the world's most dynamic players in the sector of energy utilization. In this article, the importance of harnessing waste biomass to provide relief to the issue of energy crisis has been articulately dealt with. Relevant to our times, this topic is finally getting the attention it deserves.

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Shafaq Ahmed
Kolkata

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INDIA ADDS 5,400 MW WIND POWER CAPACITY IN 2016/17

The Ministry of New and Renewable Energy (MNRE) has set another record in the wind power capacity addition by adding over 5,400 MW in 2016/17 against the target of 4,000 MW," the ministry said in a statement. According to the statement, this surpassed the previous higher capacity addition of 3,423 MW achieved in 2015/16.

The leading states in wind power capacity addition during 2016/17 were Andhra Pradesh (2,190 MW), Gujarat (1,275 MW), and Karnataka (882 MW). Madhya Pradesh, Rajasthan, Tamil Nadu, Maharashtra, Telangana, and Kerala reported 357 MW, 288 MW, 262 MW, 118 MW, 23 MW, and 8 MW wind power capacity addition, respectively, during 2016/17.

During 2016/17, MNRE took various policy initiatives in the wind energy sector, including introduction of bidding, re-powering policy, draft wind-solar hybrid policy, and new guidelines for development of wind power projects. EF

Source: The Satesman

SOLAR POWER TARIFF DROPS TO ALL-TIME LOW OF ₹2.62 PER UNIT

Solar power tariff has dropped to a record low of ₹2.62 per unit in the auction conducted for Bhadla Solar Park. The price is even lower than NTPC's average coal-based power tariff of ₹3.20 per unit.

"Bhadla Ph-IV Solar Park results in a historic lowering of tariffs. Phelan Energy (50 MW) and Avaada Power (100 MW) have bagged projects at ₹2.62/unit. Softbank Cleantech has won 100 MW capacity at ₹2.63/unit," a senior official said.

After the auction, Power Minister Shri Piyush Goyal tweeted "Another milestone towards Prime Minister Shri Narendra Modi's vision of clean affordable power for all: Bhadla Solar Park achieves tariff of ₹2.62/unit."

In April 2017, the levelized solar power tariff had dropped to all-time low of ₹3.15 per unit in an auction of a 250 MW project at Kadapa in Andhra Pradesh. Earlier in February, the lower capital expenditure and cheaper credit had pulled down solar tariff to a new low of ₹2.97 per unit for the first year in an auction conducted for 750 MW capacity in Rewa Solar Park in Madhya Pradesh. However, the levelized tariff for Rewa project has worked out to be ₹3.30 per unit. EF

Source: The Indian Express

METRO PHASE 3 TO BE FULLY SOLAR POWERED

The Delhi Metro Rail Corporation (DMRC) signed three power purchase agreements and unique co-ordination scheduling agreement on April 17, 2017, for 25 years period with Rewa Ultra Mega Solar Limited, a joint venture of Solar Energy Corporation of India and Government of Madhya Pradesh, Solar Power Developers (Mahindra, ACME Solar, and Solenergi), and MPPMCL, spokesperson for the DMRC said. The DMRC has become the first metro to procure solar power, he said.

Shri M Venkaiah Naidu, Minister of Urban Development; Shri Piyush Goyal, Minister of State (independent charge) for Power, Coal, New and Renewable Energy and Mines; and Shri Shivraj Singh Chauhan, Chief Minister of Madhya Pradesh, were present on the occasion.

The DMRC has also set a target of commissioning 20-MWp rooftop solar plants by end of 2017 on its premises and has successfully commissioned 16-MWp capacity till date.

Source: The Tribune

BENGALURU GETS WASTE WATER PLANT THAT GENERATES POWER

In what could be its maiden step towards waste-to-power ambitions, Bengaluru got its first sewage treatment plant (STP) that generates 1 MW of power using a biogas engine on May 15.

Chief Minister Shri Siddaramaiah inaugurated the STP of 60 million litres per day (MLD) capacity in the Koramangala-Challaghatta Valley, which will reduce sewage inflow into the heavily polluted Bellandur Lake by at least 120 MLD.

The state-of-the-art plant harnesses all the sewage generated by areas between Kanakapura Road in the south and Sarjapur Road in the southeast and uses the activated sludge process with biological nutrient removal (BNR) technology to generate 1 MW power. Officials said that the treated water from the STP will be used to fill up tanks in the parched Kolar district.

The Japan International Cooperation Agency (JICA) assisted in the construction of this ₹205-crore plant. The project involved laying of a 15-km long pipeline and 60 km of electrical cables and took three years to be completed.

Source: The Times of India

RENEWABLE POWER SAVES THE DAY FOR GUJARAT

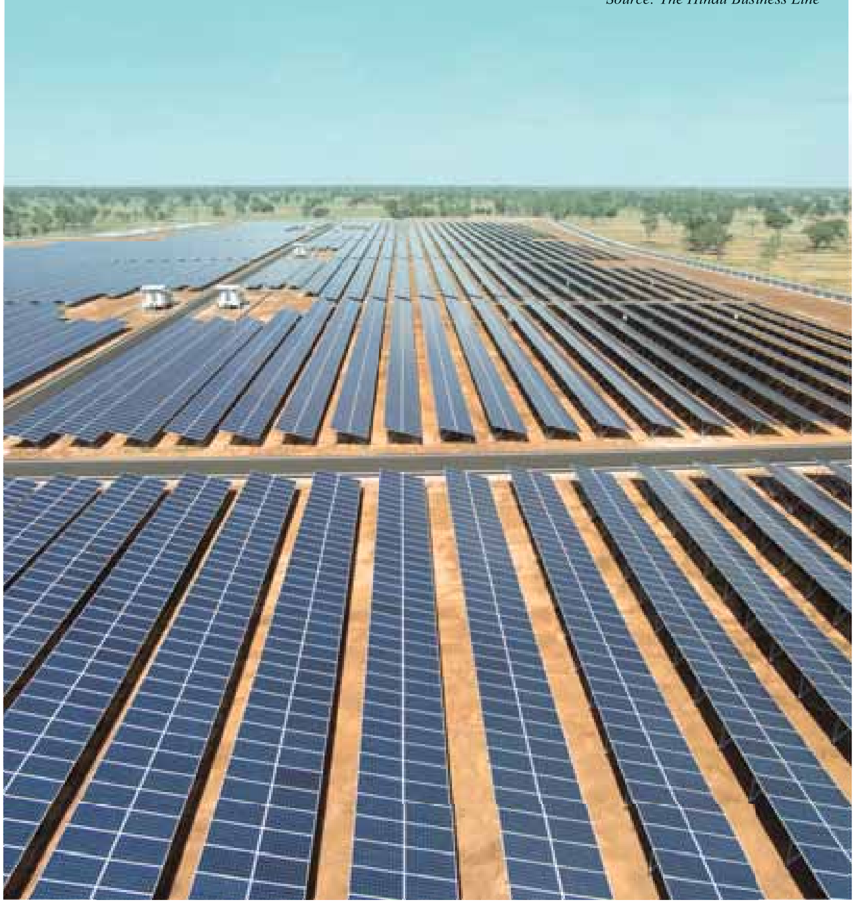
At a time, when private thermal power producers including Adani Power, Tata Power, and Essar Power have discontinued electricity supplies to Gujarat citing financial non-viability, the State continues to be on strong footing even at the peak of summer, thanks to renewable capacities in wind and solar power generation.

The leading three private power producers, which had committed to supply power to the tune of combined 5,171 MW to Gujarat Urja Vikas Nigam Ltd (GUVNL) through their respective Power Purchase Agreements (PPAs) have started phased discontinuation of power supply to the DISCOMs.

However, the companies' decision is not likely to create panic for the power-surplus State, which has over 5,000 MW flowing in from the renewable sector—1249.5 MW under solar and 4,975 MW under wind power—of the total 20,595 MW it consumes, as per the data shared by the State Load Despatch Center (SLDC) under Gujarat Energy Transmission Corporation (Getco).

"Currently, our daily requirement is in the range of 12,000 MW to 15,000 MW. And we have adequate arrangements to meet our requirements. There is no panic, the State has over 25,256 MW installed capacity. There is no chance of power shortfall in the State. There can be some escalation in cost due to old units not operating at the higher efficiency," Shri Chimanbhai Sapariya, Gujarat Energy Minister, said. EF

Source: The Hindu Business Line



INDIA PIPS US ON RENEWABLE ENERGY INVESTMENT, BUT TRAILS CHINA

India has overtaken the US to become the second-most attractive country after China for renewable energy investment, according to a report by UK accountancy firm EY. In an annual ranking of the top 40 renewable energy markets worldwide in terms of allure, China was ranked at the top, followed by India.

The US slipped to the third spot from the first in the last year's ranking, EY said. "The fall—the first for the US since 2015—to third in the ranking of the top 40 countries follows a marked shift in US policy under the new administration," it said.

India was ranked third on the last year's EY renewable energy country attractiveness index (RECAI) behind the US and China. EF

Source: The Financial Express

BIO-METHANATION PLANT TO GENERATE 400 UNITS OF POWER EVERY DAY

The Corporation's first bio-methanation plant, constructed at a cost of ₹90 lakh at Veeranam, Cuddalore district, Tamil Nadu, is expected to generate 400 units of electricity every day and serve the needs of three corporation buildings in the area. The plant has the capacity to process five tonnes of waste per day.

Of the 320 tonnes municipal solid waste generated every day in the city, more than 60 tonnes of biodegradable solid waste, including vegetables, banana trees, and others, were disposed at Chettichavadi. Vegetable waste generated at VOC market is over 50 tonnes every day, and hence, it is the main source of raw material for the plant. By processing the waste, methane-rich biogas will be generated that will be used for tubelights and other electrical items at the Animal Birth Control (ABC) centre, for operating lights and motors in the nearby water tanks, and public toilet in the area.

Since existing lights are converted into LED lights, the power from the plant could be used for more buildings. Construction of compound wall and flooring is expected to be completed in two weeks, after which the plant will be operated. Currently, trial run is in progress at the plant. EF

Source: The Hindu

VISAKHAPATNAM RAILWAY STATION TO GET SOLAR UNITS SOON

In an attempt to go green, the Waltair railway division is planning to set up rooftop solar plants at the city railway stations and other offices in public–private partnership.

One bidder from Renew Solar Power Private Limited, Gurugram, has been finalized with which the Waltair railway division will have a tie-up for 25 years. The division which has signed Power Purchase Agreement with the lowest bidder for generating and supplying of 1 MW power from rooftop solar panels will start the project soon.

The solar panels would be set up in service buildings, including Vizag Railway Station, DRM Office, Divisional Railway Hospital, Electrical Loco Shed, and Diesel Loco Shed. Similar installation of rooftop solar panels was initiated in Secunderabad Railway Station a few years ago; also North Western Railways have implemented the system.

"If all goes well the installation works will be done by July-end. The developer would be responsible for designing, engineering, procurement, erection (including civil and structural works), installation, testing and commissioning of the solar panel systems for 25 years after commissioning of the project," said a senior railway official. EF

Source: The New Indian Express

ICELAND DRILLS 4.7 KM DOWN INTO VOLCANO TO TAP CLEAN ENERGY

It's named after a Nordic god and drills deep into the heart of a volcano: "Thor" is a rig that symbolizes Iceland's leading-edge efforts to produce powerful clean energy. If successful, the experimental project could produce up to 10 times more energy than an existing conventional gas or oil well.

Launched in August 2016, drilling was completed on January 25, 2017, reaching a record-breaking depth of 4,659 m. At this depth, engineers hope to access hot liquids under extreme pressure and at temperatures of 427°C, creating steam that turns a turbine to generate clean electricity.

But the new geothermal well is expected to generate far more energy, as the extreme heat and pressure at that depth makes the water take the form of a 'supercritical' fluid, which is neither gas nor liquid.

"We expect to get five to 10 times more power from the well than a conventional well today," said Albert Albertsson, an engineer at the Icelandic energy company HS Orka, involved in the drilling project. To supply electricity and hot water to a city like Reykjavik with 212,000 inhabitants, "we would need 30–35 conventional high temperature wells" compared to only three or five supercritical wells.

Scientists and the team working on the "Thor" drill project have two years to determine its success and the economic feasibility of the experiment, which is called the Iceland Deep Drilling Project (IDDP). EF

Source: The Hindu

SMALLEST NATION JOINS SOLAR ALLIANCE

The world's smallest republic—the tiny island nation of Nauru—has become the sixth country to ratify the International Solar Alliance (ISA) Framework pact initiated by the Indian and French Governments at the climate change summit held at Paris in 2015.

Five more nations from Africa—Comoros, Cote d'Ivoire, Somalia, Ghana, and Djibouti—have committed to sign the pact during the on-going meeting of the African Development Bank in India.

Nauru, which has a population of just 10,200-odd, is particularly vulnerable to the adverse effects of climate change, said the country's Commerce, Industry and Environment Minister Aaron Cook. "Nauru has a hot and humid climate due to its proximity to the equator. We are fortunate that we don't normally experience cyclones," Mr Cook said, adding that 30% of the country's needs are currently met through solar power installations and it had set a target to attain 50% of energy production from renewable sources by 2020. EF

Source: The Hindu

'SPECTACULAR' DROP IN RENEWABLE ENERGY COSTS LEADS TO RECORD GLOBAL BOOST

Renewable energy capacity around the world was boosted by a record amount in 2016 and delivered at a markedly lower cost, according to new global data—although the total financial investment in renewables actually fell. The new renewable energy capacity installed worldwide in 2016 was 161 GW, a 10% rise on 2015 and a new record, according to REN21, a network of public and private sector groups covering 155 nations and 96% of the world's population. New solar power provided the biggest boost—half of all new capacity—followed by wind power at a third and hydropower at 15%. It is the first year that the new solar capacity added has been greater than any other electricity-producing technology. EF

Source: The Guardian

RUSSIA TAKES TENTATIVE RENEWABLES STEP

Better known for its substantial hydrocarbon reserves, and heavy carbon emitting oil and gas production, recent signals tentatively suggest that Russia is inching towards diversifying its energy mix by expanding development of alternative renewable energy sources.

While Russia has long been a global leader in hydropower production, the nascent move towards alternative renewable energies should principally be viewed in the context of a concerted government-led drive to create sustainable, domestic wind and solar power industries, with state and semi-state-backed corporations so far accounting for the vast majority of recent investment.

With a broad diversity of environmental conditions and natural resources emanating from the country's expansive geography, Russia's capacity to become a global powerhouse in renewable energy production has long been recognized. EF

Source: BreakBulk

MAURITIUS: RENEWABLE ENERGY—THE OCEAN AS AN ALTERNATIVE GREEN ENERGY

A one-day workshop focussing on the study on High Penetration Renewable energy roadmap, wave resource assessment and wave-integrated micro grid design in Mauritius was held recently in Bagatelle. The study launched in November 2015, aimed at exploring the prospects of developing wave energy and harnessing the potentials of ocean energy in Mauritius and Rodrigues. A roadmap for Mauritius, a detailed design of a microgrid for Rodrigues and a wave resource assessment were presented during the workshop. Participants from various organizations made several recommendations to the government with regard to the way forward in implementing the project.

In his address, the Deputy Prime Minister, Mr Ivan Collendavelloo underlined that Mauritius has steadily progressed in its mission of developing wave energy and is poised to gain considerably for its future by securing its sustainable, replicable, and economically viable sources of energy. This project will enable the country to achieve its energy security and in the long run help to exceed the expected target of generating 35 % of electricity production from renewable energies. EF

Source: allAfrica

GREAT RESOURCES SEES 'ENORMOUS' BIOMASS MARKET

Great Resources Co Ltd, a biomass heating provider, expects to achieve 50% sales growth this year, and plans to set up a research centre on the possible uses of straw. The company, based in the northeast city of Jilin, mainly develops biomass heating systems for homes and commercial users. Most commonly used types of biomass for such energy include agricultural residues, and urban and industrial waste. Hong Hao, chairman of Great Resources, said the use of biomass for heating has clear advantages over fossil fuels, citing sustainability as an example. "Biomass heating technology, especially the use of straw, might have an 'enormous market' in the future," Hong said.

So far, nearly 20 households in the nation's northern provinces of Jilin, Shandong, and Shaanxi have adopted Great Resources' heating technology. The total heating area has exceeded 1 million square metres, according to the company. Meanwhile, it has lowered its carbon footprint by the equivalent of 59,300 metric tonnes of carbon emissions, and 547.2 metric tonnes of sulphur dioxide emission.

"In China, biomass has been drawing attention for its role as a reliable source of renewable heat in recent years. An efficient biomass industry would serve as an effective solution for climate change," said Cheng Xu, a professor of China Agricultural University. EF

Source: ChinaDaily.com.cn

GERMANY HELPS VIETNAM EXPAND WIND POWER DEVELOPMENT

The project 'Support to the Up-Scaling of Wind Power' in Vietnam funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) was reviewed in a seminar in Hanoi. According to General Director of the General Directorate of Energy under the Ministry of Industry and Trade Dang Huy Cuong, Vietnam's electricity industry has been facing great challenges, including the shortage of energy sources for power generation. Vietnam has actively worked to ensure the national energy security, and implemented commitments relating to reduction of greenhouse gas emission and environmental protection.

The Prime Minister approved several programmes to encourage the development of new and renewable energy sources, including the Renewable Energy Development Strategy to 2030, with a vision to 2050, which aims to increase the production of wind power to 2.5 billion kWh by 2020, around 16 billion kWh by 2030 and 53 billion kWh in 2050. Experts said that Vietnam boasts great potential for developing wind power as it has a coastline of 3,000 km, and is in a tropical monsoon climate. They stressed that legal and market regulations of Vietnam should be fine-tuned to make it easy for investors to expand their operation in the field. EF

Source: vietnamplus

RENEWABLE ENERGY: HERE COMES THE SUN

Five thousand trillion kWh per year energy incident over India's land area makes solar a very lucrative option. However, factors like absence of manufacturing facility for silicon wafers, viability of projects due to progressively lower tariffs and looming grid management issues could create roadblocks.

Given the recent developments, Andhra Pradesh has emerged on top in terms of cumulative solar project capacity, surpassing the traditional solar leaders—Rajasthan and Gujarat—to report the highest installed solar generation capacity till March 2017. There are many compelling factors favouring India taking a leadership role in the solar sweepstakes.

India is endowed with vast solar energy potential, with about 5,000 trillion kWh per year energy incident over the country's land area and most parts receiving 4–7 kWh/sq.m/day. The continuing precipitous slide in solar tariffs has led to a further reaffirmation of the solar story, encouraging both developers and lenders. On June 7, 2017, the State Bank of India—the country's largest bank—announced financing of rooftop solar projects worth ₹400 crore with private developers by way of a loan of $625 million from the World Bank for on-lending to viable Grid-Connected Rooftop Solar PV projects for installation of rooftop solar systems on the rooftops of commercial, institutional, and industrial buildings. EF

Source: The Indian Express

INNOVATIONS FOR SUSTAINABLE FUTURE

Laying the Concept Base for New Energy Technologies

India is committed to climate change mitigation and has promised the world to play an important role. This has to be achieved while enabling economic and social growth of the country. Energy and its availability is crucial for the development of the people and society. To achieve this while protecting the environment, the role of technology is unparalleled. In this article, **Dr Suneel Deambi** talks about the various emerging green energy technologies that are posed to pave the road for the future.

Modern living is mired in a blend of natural and manmade complexities. Today's world is increasingly dependent on the use of gadgets. This is a direct outcome of the technological innovations that are sweeping mankind. Electricity generation and availability for all is a requisite measure of economic development. Take for example, the conventional power scenario in India which makes use of the fossil fuels, such as coal, oil, and gas. It leads to the greenhouse gas (GHG) emissions led by the infamous carbon to stress the gravity of the issue. As such, carbon capture and storage (CCS) is a technology that is capable of capturing up to 90% of the carbon dioxide emissions produced from the use of fossil fuels. Such a fossil fuel use is witnessed in electricity generation and industrial processes, and the immediate challenge lies in disallowing carbon dioxide from entering the atmosphere in no uncertain terms. Global outlook is now strongly geared towards the possible realization of carbon-free place. It for sure seems to be a tall challenge in more ways than one.

Renewable energy technologies, more so solar and wind, are fast driving the energy revolution around the world. However, their lacuna is their prevalence for short periods as well as the intermittency associated with them. Most of us have been silent users of primary and secondary batteries for breathing life into several gadgets, such as emergency lights, smartphones, laptops, and so on, which indicates the growing use of battery storage systems or simply energy storage systems. An additional issue at hand is the exorbitant per unit cost for the available storage batteries.

This can be best dealt with by mixing more than one energy source together. This rare combination of solar and wind energy sources prevalent at a site during varied periods of the day is more commonly known as the hybrid system. The underlying rationale is to provide increased system efficiency as well as to attain enhanced balance in the energy supply.

Technological choices are based on the process flows in distinctive ways. One of the most watched flows is the conversion of fast-moving winds into useful electricity via a wind turbine. The turbine directs the wind flow in a manner so as to be captured by it. Today's wind turbines have progressed from a mere 26 kW monolithic unit into a few megawatt-sized machines. Innovations of different kinds have been sweeping this wind flowing machine in increasing magnitudes of energy delivered, reduced machine weight, subdued noise levels, etc., than never before.

Energy utilization is finding its way anywhere and everywhere even though in differing magnitudes of scale, efficiency, and more importantly, outreach. India, for example, is widely dispersed in terms of habitations, where it becomes difficult to take the grid power. In such locales, both the mini and

micro grid design configurations come into play. A mini grid is a system having a renewable energy-based electricity generator (typically with a capacity of 10 kW and above). It is capable of supplying electricity to an identified set of consumers across different sectors of our energy economy, that is, residential, commercial, institutional, and industrial, via a public distribution network. In contrast, a micro-grid is akin to a mini grid but having a renewable energy-based generation capacity below 10 kW. A feature unique to both the mini and micro grids is that they usually operate in isolation to the electricity networks of the DISCOM grid. However, they can also interconnect the grid to exchange power. In that case, they are better known as grid-connected mini/micro grids.

Nature's bounty is all pervasive and impressive in more ways than one. As we grapple with the challenges of finding long-lasting alternatives to imported petroleum fuels, nature's vegetation, that is, *Jatropha* comes to mind. Oil contained in these leaves can be extracted and utilized to drive a fleet of roadways buses or cars as a case specific example. That is not the lone exception as sugarcane derived ethanol has also been meeting the same requirement. Today, ethanol-driven vehicles are fast gaining popularity worldwide. Petrol is substituted with about 10%–20% ethanol under an efficiently performed blending process to reduce consumption and thus save the valuable foreign exchange outgo even though to a limited extent. This is what is typically known as a biofuel alternative for transportation purpose.

Current CCS Activity in India

CCS phenomenon is fast catching the attention of many. India is fully concerned about this issue. The Department of Science and Technology (DST) is a premier organization in India that oversees such activities. This department put in place a national programme on carbon sequestration research almost a decade back. The following four thrust areas of research came up under the sharp focus initially:

» Policy development studies;
» Carbon dioxide specific sequestration via micro algae bio-fixation techniques;
» Carbon capture process development;
» Network terrestrial agro-forestry sequestration.

A wide spectrum of academic, research, industrial organizations has taken the mantle of enabling the CCS from several key considerations. More than 23 projects were approved for detailed investigations in various research and development centres/laboratories. Important outcome of such projects has been consolidated for a wider programme outreach. Table 1 lists a selective few research and development (R&D) projects along with their respective periods of approval.

Importantly, Indo-Norwegian joint research projects in climate research are being pursued. Such initiatives are on stream in the industrial organizations too. For example, ONGC is contemplating setting up a pilot experimental EOR project in Gujarat. Table 2 highlights a selective few key initiatives for CCS at a commercial level.

Energy Storage

Energy storage is much like saving money and consuming it in a wise manner. The most common form of energy storage is battery storage which plays a pivotal role in the integration of renewable energy sources. Today sufficient technologies and capabilities are present in the energy storage area,

Table 1 R&D projects on CCS with their details

Title of Project	Undertaken By	Year of Approval	Project Duration (Years)
Experimental and simulation studies on carbon dioxide sequestration using solar/chemical techniques	Centre for Energy, Environment, Science and technology (CEESAT), National Institute of Technology, Tiruchirappalli	2007/08	3
Analysis of CCS technology vis-à-vis the Indian power sector	Integrated Research and Action for Development (IRADE)	2007/08	2
Predicting soil carbon changes under different bio-climatic systems in India	National Bureau of Soil Survey and Land Use Planning, Nagpur	2007/08	3
A bio-electrical chemical system for sequestration of carbon	Dr Y Y Y Patil Biotechnology and Bioinformatics Institute, Pune	2011/12	3
Development of carbon composites materials for CO2 capture	Indian Institute of Chemical Technology, Hyderabad	2010/11	3
Carbon sequestration by mineral carbonation in cement kiln dust	Indian Institute of Technology, New Delhi	2010/11	3
Evolution of RuBis Cohypermorphs for enhanced CO2 sequestration and its utilization for polymer products	Bharathidasan University, Tiruchirapalli	2010/11	3

Table 2 Industrial initiatives in CCS

ONGC Ltd	Pilot setting up of an experimental EOR for a project in Gujarat Plan to utilize carbon dioxide from Hazira Gas Power Plant at an oil field at Ankleshwar with a plan to produce a high-purity gas stream from the offshore Hazira plant
National Aluminium Company	Plan to set up a carbon capture unit at its coal-fired plant at Angul, Odisha Grow algae in shallow ponds and CO_2 produced from the thermal power plant to be tapped and introduced in the pond. Algae to be utilized for production of biofuel, poultry, pharmaceutical products, etc.
Department of Chemical Engineering, IIT Mumbai	Development of cyanobacteria which can act as an excellent microbial cell factory for the possible harvesting of solar energy and convert atmospheric carbon dioxide into useful products
Bharat Heavy Electricals Ltd. in association with APGENCO	Setting up a 125 MW demonstration IGCC plant in Andhra Pradesh. IGCC is deemed as one of the cheapest choices for carbon capture Could possibly be used for the deployment of pre-combustion capture technology in the Indian power sector
Indian Institute of Petroleum	Working on development of new adsorbents for post-combustion carbon dioxide carbon capture

and these are going to get cheaper with time. However, the core challenge hinges around the uncertainty over the storage position within the future electricity markets. A feature unique to the storage technologies is in terms of their demonstrated effectiveness of being safe, reliable, efficient, and economical. Utilities, especially can realize big gains with the use of energy-storage technologies. As per the Energy Storage Association, the US market expanded by a whopping 284% alone in terms of megawatt-hours during 2016. The on-going year, that is, 2017, is going to witness exponential growth. *Navigant* reported a worldwide deployment of about 520 MW of new energy storage capacity in 2014 followed up by 2,276 MW of non-hydro energy storage attainment in 2015. According to yet another revelation made by Navigant, about 29.4 GW of new storage capacity to be installed globally across all the sectors with a compound annual growth of 60%.

The principal form of energy storage is going to be pumped hydropower with a market share of more than 95%. A wide range of storage technologies are commercially available with convincing success. Amongst the battery types, lithium-ion battery is expected to retain its majority market mainly due to its declining cost. *Bloomberg New Energy* Finance predicts battery technology

prices to drop down to $120 per kWh by 2030 as against more than $300 now. This price was in excess of $1,000 in 2010 making its market penetration difficult then. Importantly, majority of new storage capacity is going to be in the utility scale, possibly accounting for as much as 76% of the energy storage market in this year. As per Navigant Consulting Inc., more than 80% of 520 MW of global storage deployments through 2014 and 2015 came via the utility sector alone. This figure could touch a high of 9,000 MW of new utility-owned storage capacity by the year 2020. An important driver for utility deployment of storage is growth in intermittent wind and solar power. The frequency response and regulation market may continue as one of the best near-term opportunities for storage.

Perhaps the next largest market through 2017 is expected to be in the commercial and industrial (C&I) sector with a likely market share of around 21%. This could go to as high as 37% in the year 2020. It is quite appropriate to mention here that the still untapped potential is in C&I and micro grid solutions. This optimism is largely driven by the reducing prices of battery, rising energy prices, together with the growing demand for renewable energy sources, more so solar photovoltaics. Significant potential of microgrid solutions also brings many opportunities for the energy-storage developers. At present, Germany happens to be one of the world's largest storage markets worldwide.

Turbines Witnessing Innovation

Wind power gained acclaim worldwide even before solar photovoltaic was considered for grid-connected power generation. The free-flowing wind is used through the bladed wind turbines. These machines now perform reliably and safely in capacity ratings ranging between 500 kW to 3,000 kW and above. This marks a rapid departure from the early days of wind turbines being available in just a capacity rating of a few kilowatts. Thanks to the path-breaking innovations in the wind turbines that enable these to function even without gear box. Table 3 gives a quick insight into such developments from several key considerations.

In totality, presence of these combined attributes in the wind turbines has gradually led to capacity ratings of 2.5–3.0 MW. The available power capacity utilization factor can even be 50% for a wind farm size of about 500 MW. It is certainly a marked departure from the early days of wind turbine development when their capacity ratings were hardly ranging between 25–60 kW.

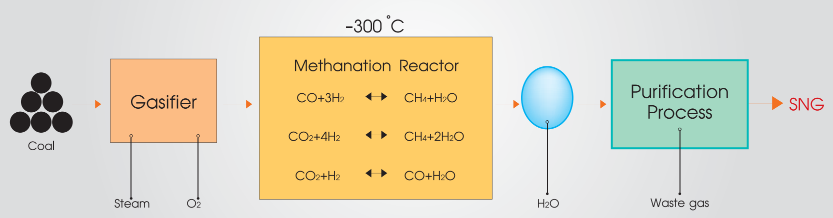
Biofuels

Biofuel is mainly derived from *Jatropha* plant can be used as a fuel for transportation under the alternate

Table 3 Key innovations in wind turbines

Innovative Parameter	Key Remarks
Height of the wind turbine	The taller wind machines are capable of catching more wind and the wind is stronger higher off from the ground
Moving (i.e., mechanical) efficiency	Modern-day wind turbines have no gearboxes at all thus bringing down the complexity and losses associated with the gearing
Size of the blade	Higher wind conditions get converted by narrower blades with size of generator being large and vice versa
Improvement in aerodynamics	More aerodynamic lift comes into play owing to changes in their shape via their length to bear with different relative air speeds between tip and hub
Ease of maintenance	Modern-day wind turbines now witness around 98% availability to produce electricity, both due to improved technology and efficient maintenance practices
Robust design	The wind machines now exhibit better tolerance for high winds, icing, and other realities of exposed parts
Improved wind modelling	Enhanced clarity and understanding together with sophisticated modelling procedures now result in more accurate estimations of wind machine capacities under actual site-specific conditions
Incorporation of guided instrumentation and automation	Computerized abilities of today make it possible to adjust to maximize power output under varying wind regimes. Availability of real-time updates via the use of SCADA interfaces for those managing the wind farms and associated grid operation
Advancement in the material types	The material in use for the blades is being refined on more or less a regular basis. Stronger and lighter blades ensure more efficiency and robustness too

Conventional process for the production of SNG from coal gasification



fuel category. The Ministry of New and Renewable Energy (MNRE), Government of India, came up with a biofuel policy as early as in 2009 with a twin purpose of (a) to meet the fast-increasing energy needs and (b) to provide the much-needed energy security. Significant objective of the policy is along the following few vital considerations:

- Development cum utilization of indigenous non-food feedstocks raised from degraded or waste lands;
- Heightened impetus on cultivation-based research and development activities;
- Processing and production of biofuels;
- Scheme for blending of 20% biofuels and ethanol by 2017.

The underlying rationale of the biofuel policy is to support R&D, pilot plant/ demonstration projects aimed at the commercial development of second generation biofuels. MNRE supports such projects for efficient development of technologies for biofuel production via the routes of (a) biogas and (b) pyrolysis and gasification. The larger purpose is to encourage deployment of technologies for both the pilot and full-scale projects on biofuels in general.

Simple Definition and Policy Directions

Biofuels happen to be liquid or gaseous fuels that are typically produced from the biomass resources. These are used in place of, or in addition to diesel, petrol, or other fossil fuels for diverse end uses, such as transport, stationary, portable, and other applications. In turn, the biomass resources are the biodegradable fraction of products, wastes, and residues from agriculture, forestry, and related industries as well as the biodegradable fraction of the industrial and municipal wastes. The broad scope of MNRE policy envisages bioethanol, biodiesel, and other biofuels:

- *Bioethanol*: Ethanol produced from biomass such as sugar containing materials, for example, sugarcane, sugar beet, sweet sorghum, etc.;

» Starch-containing materials, such as corn, cassava, algae, etc.;
» Cellulosic materials, such as bagasse, wood waste, in addition to agricultural, forestry residues, etc.;
» *Biodiesel*: Methyl or ethyl ester of fatty acids, which is normally produced from vegetable oils, both edible and non-edible or animal fat of diesel quality;
» Other biofuels. such as biomethanol, biosynthetic fuels, etc.

Micro and Mini Grid System Design Configurations

Rural areas are finding utilization of solar and biomass resources as a great boon. From stand-alone units in the beginning, the existing trend is to put up newer design configurations, such as the micro and mini grid power systems. The generator of a mini grid can be powered by renewable energy sources, including wind and small hydro resources. Diesel-based generators may still be used as a power backup. Hybrid systems utilizing a combination of resources can be deployed to make the operation more reliable. As per the policy directive, use of conventional fuels, such as those derived from petroleum like diesel and kerosene, is simply to enhance the reliability of renewable energy mini grids in special cases only. The public distribution network of a mini grid can be designed to carry either AC or DC current. The AC current is intrinsic to the rotating generators, such as wind, hydro, and diesel, while solar photovoltaic is suited for DC current. Moreover, typical design choice of AC or DC use has a bearing on the project cost, appliances in use, and the interconnection conditions at large.

DC distribution is usually acceptable for low-power applications, such as those seen in lighting, radio, mobile, television, and other household appliances. This is also generally witnessed in limited geographical areas based on available voltage levels. It is also not appropriate for interconnection with the locally available grid, that is, DISCOM grid. Importantly, a combination of both AC and DC mini grids is possible. Table 4 highlights the recommended levels of both the DC micro grids and those of AC micro grids.

A mini grid is capable of meeting the electricity requirement to the consumers for various end-use applications. Table 5 gives a schematic representation of the

Table 4 Recommended voltage levels and design capacities of AC and DC grids

Grid Type	Voltage Levels	System Design Capacities
DC micro grids	24 V 72 V	Up to 1 kWp • 1 kWp to 10 kWp
AC micro grids	220 V single phase 440 V three phase	• Up to 10 kWp • More than 10 kWp

most important consumer categories for the purposing of being served through these micro/mini grid systems.

Key Elements for Mini Grid Costing

The cost of a mini grid comprises of both fixed and variable types.

Fixed type

» Project development
» Generation facility
» Storage system (i.e., batteries)
» Inverters
» Distribution network
» Cost of availing debt (including the interest charges)
» Fixed taxes and fees (i.e., on land and infrastructure)
» Project management cost

Variable

» Operation cost
» Maintenance cost (in relation to plant runtime/output, load-dependent technical losses in inverters, transformer, and storage medium too
» Local running costs

Table 5 Consumer categories and applications within these categories

Type	Potential Applications
Households	Lights, Television, Fan, Mobile charging, etc.
Agriculture	Water pumping systems for irrigation and related uses
Commercial	Shops, Ice makers, Battery/Lantern charging (including those for renting), Telecom towers, etc.
Social institutions	Educational institutions (such as schools), Health centres, Public buildings and community outreach buildings, Government offices, Panchayat offices
Municipal needs	Street lighting, etc.

Today, several companies in India are actively involved in setting up of micro and mini grid power systems. Monthly payment facility to the users is available via options such as pre-payment cards; it is equivalent to 'pay for electricity as you use' and acts as a necessary safeguard for the project developers.

WE NEED TO ADOPT CARBON EMISSION-FREE PRODUCTS AND SERVICES FOR SURE. THAT ALONE IS A GUARANTEE FOR ACHIEVING A CARBON-FREE PATH THAT IS GOING TO BE BENEFICIAL FOR THE COMING GENERATIONS.

The Carbon-Free Path Forward

Global warming is becoming a formidable reality as is experienced by the masses. As economic development occurs in several parts of the world on a more noticeable scale, use of greenhouse gas emissions appliances is also going up. Take, for example, an air conditioner running in our houses during the on-going intense heat of summer. It cools the interiors but throws up the warm air outside. We need to adopt carbon emission-free products and services for sure. That alone is a guarantee for achieving a carbon-free path that is going to be beneficial for the coming generations. Significant R&D efforts are currently underway to reduce the carbon footprint in one way or the other. Hybrid combination of renewable energy sources, such as solar and wind, may reap better dividends in such geographical areas that have good enough prevalence of both sunshine and free-flowing wind. Likewise, biomass availability in regions closer to the forest areas or with a plentiful supply of various types of feedstock materials could be tried in conjunction with some other energy alternative.

India is going to embark on a massive programme of electric vehicles for transportation purposes in the foreseeable future. The charge of such batteries could well be adopted through a judicious mix of both the conventional and non-conventional energy choices. Centralized charging stations with solar roofs, for example, may turn out to be an aesthetically pleasing sight. It reminds me of the sight of small-capacity wind machines (say around 5–10 kW) meeting the power requirements in ONGC township within Mumbai. Battery energy storage is going to witness ever expanding areas of use if, the declining price trend continues. There is a strong likelihood of that if, for instance, electric vehicles initiatives become a new-age reality on a large scale in the short term. The final purpose is to lay a preparatory framework for moving to a carbon-free economy sooner than later. EF

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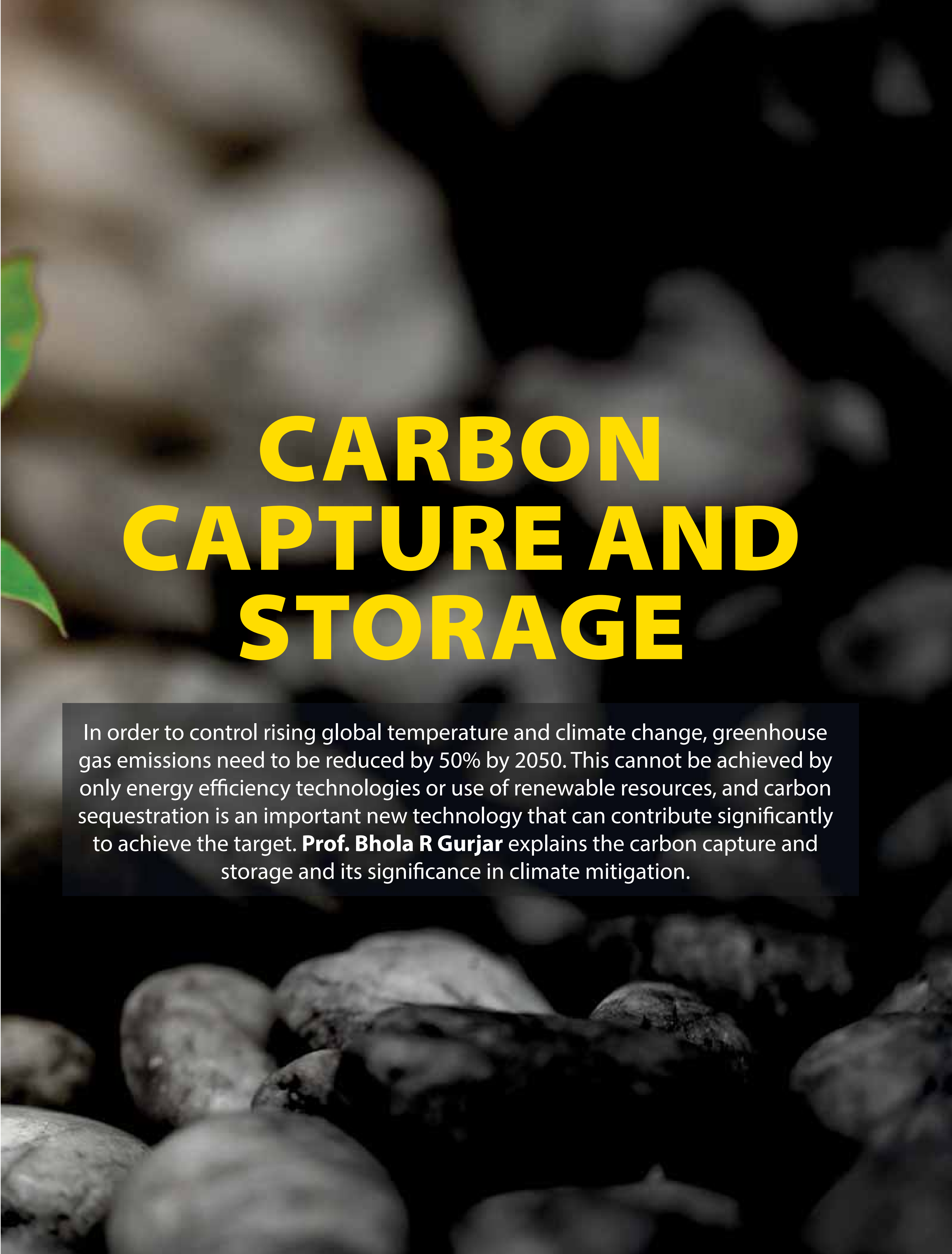


CARBON CAPTURE AND STORAGE

In order to control rising global temperature and climate change, greenhouse gas emissions need to be reduced by 50% by 2050. This cannot be achieved by only energy efficiency technologies or use of renewable resources, and carbon sequestration is an important new technology that can contribute significantly to achieve the target. **Prof. Bhola R Gurjar** explains the carbon capture and storage and its significance in climate mitigation.

In general, the process of carbon capture and storage (CSS) is associated with the segregation of CO_2 from exhaust emissions generated from fossil fuel-based industries and energy utility plants. Besides capturing CO_2 at source, this also involves its proper transportation and transformation either to some product so that the release of CO_2 into the atmosphere can be prevented for a longer term or to store it inside a secure geological location or deep inside the ocean so that it remains isolated from the atmosphere.[1] Thus, one can say that CSS is a process that can directly reduce emissions of CO_2 to the atmosphere so as to reduce global warming and climate change.

As fossil fuel is the primary source of energy in our present and immediate future, CCS can be regarded as a solution to overcome CO_2-related problems (e.g., global warming, climate change, etc.). The CCS can also be used as a resource for future. Considering the future scenario and usage of energy source, CCS tends to be a better option both in the sense of primary source and controlling environmental problems.[2]

To meet the scale of economy, CO_2 capturing has to be applied to large-point sources. At first, it is captured and then transported to the depths of ocean or any geological formation that can be used in the future for industrial purposes. Large-point CO_2 sources include industries (e.g., coal-based thermal power plants) emitting CO_2; facilities related to fossil fuel and biomass energy production; fuel produced from natural gas, hydrogen, and commercial plants. Storage sites include geological storage, such as oil and gas fields, coal beds, and deep saline formations. Another method of storage can be conversion of CO_2 into inorganic carbonates.[2]

1 Herzog HJ. 2011. Scaling up carbon dioxide capture and storage: From megatons to gigatons. *Energy Economics* 33(4): 597–604.

2 https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf

Sources of CO_2

Major Sources and Characteristics

Carbon dioxide emission arises from various anthropogenic activities, including industrial processes (such as power generation), vehicular emissions, agricultural activities, and energy usages in residential and commercial buildings. However for CO_2 capture, a large-point source has to be considered (e.g., CO_2 generated from coal-based thermal power production) as the cost of CO_2 capturing decreases when capture rate increases.[3] However, it is not possible to target all large-point sources for CO_2 capture. So on the global scale, major large sources were divided into four zones of emissions, viz., North America (midwest and eastern USA), Europe (northwest region), East Asia (eastern coast of China), and South Asia (Indian subcontinent).

Methods of Carbon Capture

Carbon Capture

Carbon-capture techniques involve different methods, such as physical, chemical, and biological processes. Technologies used by industries for carbon capturing consist of separation of CO_2 from other exhaust gases by employing one or the other techniques shown in Figure 1.

Post-combustion capture

This technique involves use of liquid solvent to capture CO_2. Different separation methods are used, such as high-pressure filter, use of organic solvent, and adsorption and desorption process. In addition, amine solvents, such as monoethanolamine (MEA), are also used these days.

Pre-combustion capture

In this process, fuel is mixed with a stream of air or oxygen in the first reactor to produce a mixture of carbon monoxide (CO) and hydrogen (H_2). Later in the second reactor, carbon monoxide reacts again with steam to produce CO_2. The resulting mixture can be separated to hydrogen and CO_2 gas streams. Hydrogen gas can be used to generate power and heat. Integrated gasification combined cycle technology has been incorporated at power plants for pre-combustion process. However, high pressure is required for the CO_2 and hydrogen separation process and the initial cost of this technology is quite high.

3 http://www.ccsreg.org/pdf/CCSReg_3_9.pdf

Oxy-fuel combustion systems

In this process oxygen is used in place of air for production of flue gas from primary fuel during combustion. This method helps in production of high CO_2 concentration flue gas. This flue gas consists of water vapour and CO_2. Water vapour is further separated by cooling and compressing the gas stream. This process is used in gas turbine systems, for which 95%–99% pure oxygen is used for combustion. Further studies have been done to increase efficiency, higher level integration of system, and to reduce cost.

CO_2 Transport

The captured CO_2 is transported for storage at some suitable site with the help of pipelines, trucks, trains, ships, or other means of transportation.

Pipeline

A large network of pipelines are used for this purpose after confirming their safety and reliability. Pipelines can transfer large amounts of CO_2 over long distances. This is the most economical method of transfer over long distances.

Land (road/rail)

This method of transportation has been used for shorter distances, where the cost of constructing pipelines is quite high. In this method, truck, train, and other such means of transportation are used for the transportation of CO_2.

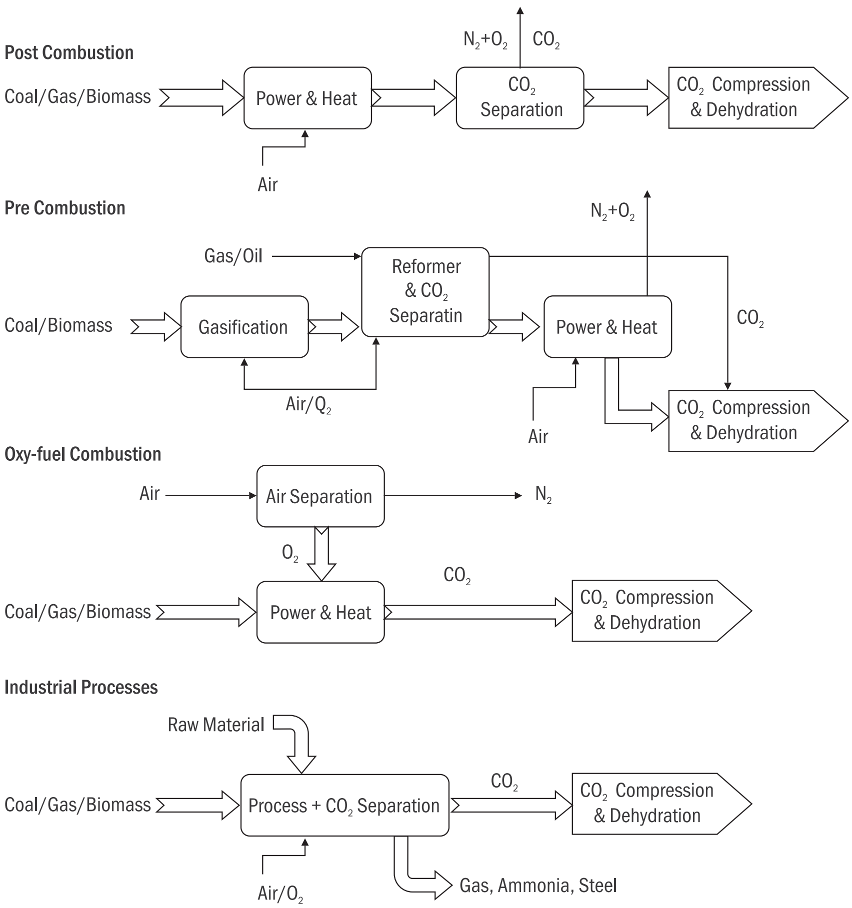


Figure 1 Various types of carbon capture processes

Shipping

This option is viable when there is need to store CO_2 gas in some offshore location or geographical strata. Shipping helps in transportation directly to the desired locations.[2]

CO_2 Storage

Several geographical scenarios have been used for CO_2 storage that include deep inside saline reservoirs, diminishing gas and oil fields, methane coral bed, amongst others. Storage of CO_2 in suitable geographical formations is currently used as the most common option.

Enhanced hydrocarbon recovery

This method includes enhanced oil recovery (EOR), enhanced gas recovery (EGR), and enhanced coal-bed methane recovery (ECBM). The use of any of the above methods helps in recovery of oil or gas and that can help curtail the cost of CCS.

- **Enhanced oil recovery (EOR)**: In this technique, CO_2 is injected in a reservoir with high pressure that further results in converting CO_2 gas to fluid. Therefore, CO_2 is permanently transferred to the geological strata. Due to its fluid property, it can be easily extracted for future use. EOR has economic value where a shorter distance has been used to transport CO_2.[2,3]
- **Enhanced Gas Recovery (EGR)**: In EGR technique, CO_2 is injected into the bottom of gas reservoir with pressure. As CO_2 is heavier, it moves to base of reservoir and allows natural gas to float to the top. By this method, high amount of natural gases get extracted from many gas fields while simultaneously helping in carbon storage.[2,3]
- **Enhanced Coal Bed Methane Recovery (ECBM)**: In ECBM technique, CO_2 gas is stored in coal beds (known as coal seams). The CO_2 has high affinity to get adsorbed into the coal surface. It is because of the presence of pores and fracture on the coal bed surface that can easily adsorb gases. This method allows methane recovery along with CO_2 storage; while CO_2 gets adsorbed at the surface, it displaces the remaining methane from the adsorption sites. However, there are some drawbacks of the ECBM method, such as low permeability of gas at coal beds site, which necessitates a large number of coal beds. Moreover, methane in the coal beds symbolizes only a small percentage of the energy value, and to extract the remaining portion of coal as an energy output, it needs to be mined or gasified so that it could not discharge CO_2 to the atmosphere. Finally and most importantly, methane is a more potent greenhouse gas (GHG) than CO_2. So, steps have to be taken to safeguard its leakage to the atmosphere.[2]

Other alternative techniques for carbon storage

In spite of storage to the geological strata, CO_2 could be utilized in the manufacturing of dry ice, polymer, and carbonic acid production. Unfortunately in these cases, CO_2 would again be released to the atmosphere. The only benefit is that it would substitute the supply of CO_2 for industrial purposes. Carbon dioxide can also be used for biomass cultivation, algae formation, mineralization in the form of silicates, and adsorption in mineral ore reservoir.[2]

Barriers to Carbon Storage

The CCS is an emerging technology aimed at 50% reduction in CO_2 emissions by 2050 for preventing global warming. However, there are opportunity costs for every innovation or improvement in state-of-the-art technologies. For example, in the United States, the extra cost of introducing CCS on CO_2-emiting sites is an essential hurdle to the appropriation and organization of CCS. Significant increments in efficient CO_2 capture technologies will probably create the best relative cost reductions for CCS frameworks, yet the transport and storage segments of CCS will still remain a challenge. Ideally, storage repositories for CO_2 would be found near sources, deterring the need to construct a substantial pipeline framework to convey the captured CO_2 for underground sequestration.

In future, however, when CCS becomes a widespread practice, a few regions of the nation might not have sufficient capacity for reservoirs in the vicinity and may need to develop a pipeline system from sources to repositories. Recognizing and approving sequestration destinations would need to consider CO_2 pipeline costs. If so, there would be inquiries to be settled with respect to the pipeline system necessities, financial control, utility cost recuperation, administrative characterization of CO_2 itself, and pipeline security. Additionally issues, such as liability, ownership, and long-term stewardship for underground CO_2 sequestered have to be tackled before commercial application of CCS. Also, the public acceptance of infrastructure, expenses, and inconvenience caused due to CCS are yet to be known, which sometimes play a critical role.[4]

Economic Barriers

Cost effectiveness is the primary need for any technology to be adopted. Establishment of CCS would involve high cost of infrastructure, skilled labour, etc. Hence, widespread CCS establishment requires extensive research and development (R&D) to make the processes feasible. To consider CCS as a viable option, its cost must be competitive to the existing strategies of CO_2 reduction. Although the potential for reduction of CO_2 with CCS is much better through existing strategies, it might gain political acceptance in order to earn global carbon credit even at a comparatively high cost.[5]

Social Barriers

With economic viability of CCS, it also has to be socially acceptable. Public involvement in CCS decision-making and development processes would minimize conflict of interests. There have been instances of delays and shutdown of CCS projects globally due to public opposition such as in Barendrecht, Netherlands. Hence, researchers, policymakers, and stakeholders must actively communicate and involve local people to make them understand as well as know their perception.[5]

Legal Barriers

Numerous complex issues, for example, property rights, liability, monitoring, and verification, etc., act as regulatory and legal barriers. A versatile framework for policy, regulation, and legislation in implementing CCS is absent. As regulations differ in different countries, there must be policy modifications to include considerations for nationwide legal acceptance and suggesting a legal framework for horizontal (different regimes and their issues) and vertical (different regional, national, and international laws) effectiveness.[5]

Policy Recommendations

Research, Development, and Capacity Building

Technologically, CCS is presently deployable at a requisite size to solve the problem; however, noteworthy efforts are needed to decrease the costs. Progress is also required to create the assets (human, monetary, and specialized) that will enhance our understanding of dangers and techniques for their mitigation so as to eventually empower the markets.[6] Storage, too, demands significant capacity building, research, and development:

- Development of skilled manpower;
- Development of financial risks management system using the insurance and financial sectors;
- Research and simulations study the behaviour of geological sites for suitability as reservoirs;
- Methodological improvements in study of storage space characteristics;
- Making efforts towards cost reduction of sequestration processes;
- Quantification techniques for leakage;
- Hydro-geological data of regional and basin scale;
- Methods for remediation of process difficulties;
- Developing suitable technologies to improve yield of oils from reservoirs using CO_2 injection.

Pore Space

The ownership and right to use a given pore space can be determined without much conflicts. As per the prevalent law, jurisdiction governing construction rules conclude that owners of the surface own its pore space. In addition, mineral owners have reasonable rights on using pore space for mineral production. It is generally a wise practice to acquire pore space rights from both surface and mineral owners.[6]

Public Lands

There is a need for policy development for both onshore and offshore public lands entitling statutes to remove pore space ownership problems on site. This

4 https://fas.org/sgp/crs/misc/R42532.pdf

5 Yoro KO and Sekoai PT. 2016. The potential of CO_2 capture and storage technology in South Africa's coal-fired thermal power plants. *Environments* 3(3): 24.

6 Anderson AS and Fund ED. 2010. Carbon sequestration in oil and gas fields in conjunction with EOR and otherwise: Policy and regulatory issues. In *Role of Enhanced Oil Recovery in Accelerating the Deployment of Carbon Capture and Storage: An MIT Energy Initiative and Bureau of Economic Geology at UT Austin Symposium*. pp. 173–93.

would include segregating areas to be suitable or unfit for sequestration activities and describing provisions for acquiring lease for it. While defining such policies, sufficient considerations need to be taken towards coastal and marine environments.[6]

Transportation

A public interest perspective should be undertaken to scrutinize and permit suitable location of CO_2 transport pipeline system. Not many changes are required in safety considerations of pipelines till the purity of CO_2 does not fluctuate.[6]

Health Safety and Environmental Risks

CO_2 is nontoxic, generally harmless and inert gas, and is part of natural carbon cycle. Plants use CO_2 for photosynthesis, and it is an active component of various chemical reactions. However, in excess concentrations (>1%), it can cause certain physiological effects in humans. An increased CO_2 concentration also causes damage to other life forms and disturbs the balance of climate and the environment as a whole. Increase in global temperature, increase in pH of oceans, melting of polar ice caps, etc. are major effects of increasing CO_2 concentrations in ambient air.

Use of CCS technologies would significantly reduce CO_2 emissions but may cause side effects. A major trade-off is the actual efficiency of CO_2 capture that is significantly less than the design efficiency. There have been cases of increase of SO_2 and NO_2 emissions per kWh post-combustion but generally they are observed to decrease or remain unchanged. PM emissions per kWh post- and pre-combustion carbon capture processes tend to increase. Also, emission of VOCs though not completely estimated is suggested to occur in some post-combustion technologies.

There is a general concern regarding medium- and long-term environmental performance of CCS projects as well as safety issues, such as indoor air quality, confined space hazard, occupational safety, etc., which hinder support provisions to the CCS projects. Suitable monitoring, trapping mechanisms, site selection, and framework of procedures and legislations are essential to ensure reliability and to minimize environmental and human health risks.

The most probable risk from CCS technologies is from the failure of storage scheme in form of CO_2 leakages from abandoned wells, inadequate storage capacity estimations, and failure of injection wells. Nevertheless, a cautious site selection, continuous monitoring of nearby environment, and following necessary regulations would prevent such failures.

Legal Aspects and Regulatory Framework for the Use of CCS Technology

The CCS technology is emerging as one of the most effective method to combat GHG emissions with a view to mitigating climate change. The technology has proven to be effective in capturing and storing large amounts of CO_2. The Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) addressed the significanct need of CCS technology to satisfy the ambitions of the Paris Agreement 2015.[7]

Legal issues related to CCS technology must be considered along with its technical feasibility in order to build CCS as a climate mitigation measure. Well-designed regulatory framework is required to address risk and liability related to CCS technology as well as to generate trust between the society and private stakeholders. This essentially includes safety issues that may occur in operation of CO_2 capture, transportation facilities, and liability of geological storage of CO_2, covering both legal and infra-legal issues to eliminate the conflicts among stakeholders. Risks associated with CO_2 capture facilities are similar to traditional power plants and other industrial facilities, which can be sufficiently regulated under the existing regulatory frameworks of developed economies. Safety issues related to CO_2 transportation facilities should also be given careful consideration. Most nations have its regulatory framework for natural gas transportation and pipelines

7 http://hub.globalccsinstitute.com/sites/default/files/publications/201158/global-status-ccs-2016-summary-report.pdf

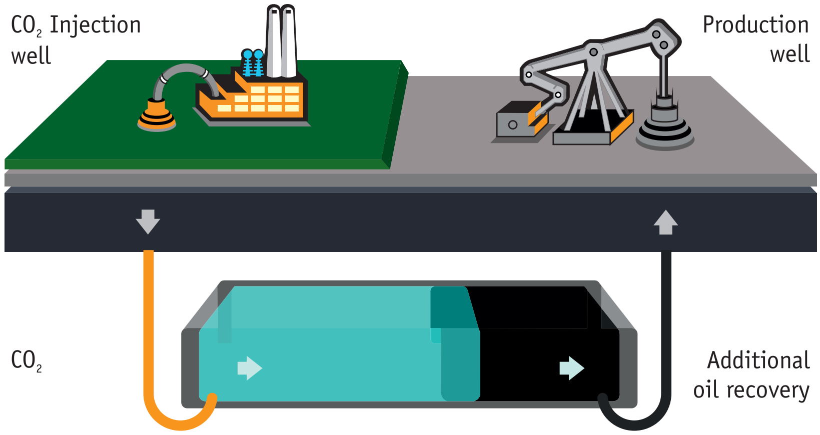
safety, which is clearly applicable to CO_2 transportation facilities.[8]

Necessary institutional and regulatory framework is required to ensure safe, environmentally sound, affordable, and socially acceptable deep geological storage/sequestration of CO_2. This regulatory framework must include various objectives to protect the health of those involved in sequestration project and to prevent degradation of adjacent groundwater, ecosystem, and mineral resources. Regulations and regulatory structure should encourage developers to minimize the long-term cost and regulatory risk of the project while still effectively accomplishing other regulatory goal.[3] A descriptive view of the regulatory and liability issues related to CCS technology can be found in Regulation of Carbon Capture and Storage.[9]

Implementation of stronger policies to the deployment CCS projects may be difficult. However, IPCC Fifth Assessment Report Summary for Policymakers highlights that costs of achieving climate change targets would be increasing by an average of 138% without considering CCS as an emission-reduction technology.[10]

CCS regulatory framework and jurisdiction may be regulated at a centralized, national, or states level or may be shared between national entities and states. Countries around the world have different structure for CCS regulatory framework. For example, in Australia, the authority over CO_2 storage onshore and ahead of three nautical miles distance in offshore is shared among Australia's federal government, states, and territories,

Enhanced oil recovery



while beyond three nautical miles offshore to the Australia's continental border is under the federal government. Similarly, the regulatory framework in Canada for CCS is dispersed between the federal and regional governments. Legislation and regulatory framework has also been structured to regulate CCS activities in offshore waters and onshore countries. Amendments were done to allow CO_2 injection and cross-border transportation of CO_2 in the London Protocol and the OSPAR Convention marine treaties, which underlined the success stories in the CCS legal and regulatory framework.[11]

CCS legal and regulatory framework can be straightforwardly regulated by customizing existing relevant laws and framework that are already in effect. In the Canadian provinces, CCS is regulated under the oil and gas production regulatory framework, whereas in Norway current petroleum and pollution-control regulation covers the CCS regulatory framework. In the United States, the US Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) has prime jurisdiction to regulate cross-border CO_2 pipelines. However, in Spain, existing mining laws have been reformed to regulate CCS. The Energy and Resources Institute (TERI) and the Global CCS Institute conducted a study in 2013 on Indian CCS Scoping, which identified various existing policy and legislation that can be applied for CCS technology.[12]

Adequate incentive-related regulatory policies are required in order to support business model of CCS project deployment, which may attract the stakeholders to adopt CCS technology. Authorities are progressively recognizing the need to grant incentives to nurture large-scale CCS deployment along with structuring clear laws and regulation. The European Union (EU) has revised the EU Emission Trading System Directives to fully incorporate CCS projects from 2012. It has also owed the profits through trade of 300 million EU ETS grants to facilitate CCS technologies. The United Kingdom had proposed putting a tax on electricity generation for backing the capital and functioning costs of CCS deployments. Some other countries have also recognized such funding opportunities in order to promote CCS technology. International organizations, such as IEA, the Global CCS Institute, and World Resource Institute, are providing widespread

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8 Zakkour P and Haines M. 2007. Permitting issues for CO_2 capture, transport and geological storage: A review of Europe, USA, Canada and Australia. *International Journal of Greenhouse Gas Control* 1(1): 94–100.

9 http://www.ccsassociation.org/docs/2008/IRGC%20Policy%20Brief%20CCS%20Regulation%20Feb%2008.pdf

10 https://www.ipcc.ch/pdf/assessmentreport/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf

11 http://hub.globalccsinstitute.com/sites/default/files/publications/196443/global-ccs-institute-ccs-legal-regulatory-indicator.pdf

12 http://hub.globalccsinstitute.com/sites/default/files/publications/88981/india-ccs-scoping-study-final-report.pdf

Kemper County Energy Facility, MS, USA; Source: Wikimedia Commons

analysis of existing and developing frameworks. They provide support to develop the regulatory frameworks and guidance to identify several CCS legal and regulatory frameworks. The IEA also offers resources via analysis and publications and foster information swapping through International CCS Regulatory Network.[13]

The Global CCS Institute's Legal and Regulatory Indicator report has carried out a detailed examination and assessment of national legal and regulatory frameworks of the 55 countries, which has shown that Australia, Canada, Denmark, United Kingdom, and the USA have scored highly within the indicators published by CCS Institute. The United Kingdom has acknowledged the strongest policy leadership in promoting CCS technology. Russia, India, and Indonesia have also indicated a strong attention in encouraging CCS technology. These results have addressed the need of strong policy commitments and identified significant opportunities for additional legal and regulatory development in other countries across the world to support the CCS technology deployment.

13 https://www.iea.org/publications/freepublications/publication/191010IEA_CCS_Legal_and_Regulatory_Review_Edition1.pdf

Present Status of CCS Technology

The Global Status of CCS 2016 Report has identified 38 CCS projects as a combination of both large- and small-scale projects in various countries. Of these, 15 large-scale CCS projects are in operation, having CO_2 capture capacity around 30 million tonnes per annum (Mtpa) and other large-scale projects, in the US, Australia, and Canada are proposed to be in operation by end of 2017.[7]

The Emirates Steel Industries (ESI), Abu Dhabi CCS Project, and Tomakomai CCS Demonstration Project, Japan, having CO_2 capture capacity of nearly 0.8 Mtpa and 0.1 Mtpa, respectively are acknowledged as two key CCS industrial sector projects launched in 2016. Oil and Natural Gas Corporation (ONGC) Ltd., India, set up a pilot experimental CCS and EOR project in Gujarat, whereas Aluminium Company (NALCO) is in process of setting up CCS project at Angul, Orissa.[12]

Successful CCS projects around the world, such as Sleipner CO_2 Storage Project, Norway, injected nearly 16 million tonnes of CO_2 effectively since 1996, and the Snøhvit CO_2 Storage Project, offshore Norway, injected more than 3 million tonnes of CO_2 since the project started in 2008. Further, the Santos Basin Pre-Salt Oil Field CCS Project in Brazil; the Air Products Steam Methane Reformer EOR Project in Texas; the Quest project in Alberta,

Canada; and the Jilin Oil Field EOR Demonstration Project in China have collectively captured and injected over 8 million tonnes of CO_2. Over 13 million tonnes of CO_2 have been injected in the US under the DOE's Clean Coal Research, Development, and Demonstration Programmes as of end 2016.

Future Directions

The idea of CCS in the present context has some unsettled issues, for example, inadequate knowledge of geographical storage and its effect on the marine environment, efficiency of a foolproof system without leakage, energy requirement, legal issues, cost benefits, and other uncertainties during the processes of collection to storage.

The CCS technologies may face primary hurdles of infrastructure and overall costs, social disputes, and legal issues from one country to another. However, it can be considered as the best bet for cutting down GHG emissions in the years to come. Extensive research and active deployment of CCS technologies in future would allow systematic analysis and upgradation of state-of-the-art practices. Such continuous improvements as well as obligatory regulations would also ensure safety of the environment and life forms in the vicinity of CCS locations. It is believed that the appropriate policies and support by individual governments for nation-wide implementation of CCS technologies would make them economically viable, socially acceptable, and legally tenable in the long term. The success of CCS projects would depend on encouraging other nations in developing and using CCS technologies, incentive mechanisms, and regulatory frameworks for providing sufficient support for the deployment of CCS technologies as has been the case in the area of clean energy technologies. Though significant advancement has been done the world over in the last few years, yet strong commitment is required to accelerate the speed of CCS deployment in order to attain the world's goals to mitigate climate change-related risks. EF

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Suggested Reading

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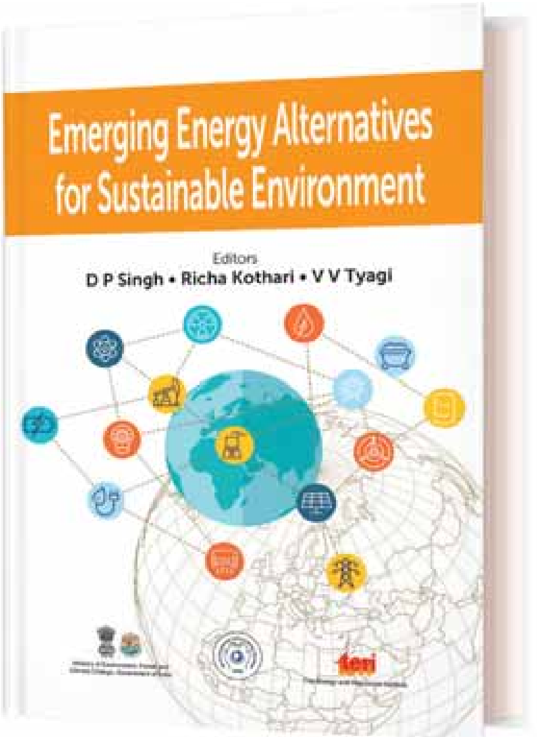

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THE CLEAN ENERGY REVOLUTION

Building Storage Capacity

Wind and solar—two of the most potent sources of clean, renewable energy—not only require adequate harnessing but efficient storage as well. This necessity gets further emphasized by the fact that renewable installations accounted for over half of the total global energy capacity addition in 2016. Given this it is no wonder that energy storage is expected to increase into a robust, multibillion-dollar business in the near future. In this article, **Viraj Desai** talks about how India's stupendous growth has attracted international investors and is expected to be a game-changer for India, especially since one-fourth of the population lacks access to electricity.

Clean energy deployment is witnessing a revolution globally. This is demonstrated clearly by the fact that renewable installations accounted for over half of the total capacity addition globally in 2016. There has been a significant shift from the fossil fuels-based electricity production and consumption throughout the twentieth and early twenty-first century. With emerging markets of India and China taking a lead in renewable installations every year, with an aim to achieve sustainable development goals as envisaged by 2030, energy storage is being looked at closely considering the intermittent generation of unconventional technology.

Electric vehicles are also being explored and the likes of Tesla Motors may make it possible to have a revolution

akin to Ford Motors appeal due to mass production in early twenty-first century.

A study conducted by the International Finance Corporation and the World Bank–administered Energy Sector Management Assistance Program, "Energy Storage Trends and Opportunities in Emerging Markets", said that the energy storage capacity is expected to surge to 80 GW, growing at a rate of 40% per annum in the next 10 years. This will present huge opportunities considering that currently there is only a small and fragmented market that exists today.

From an estimated $200-million market in 2012, energy storage is expected to grow into a multibillion-dollar business in the next few years. A recent report from Bloomberg New Energy Finance estimated that an estimated $8 billion will be invested in new-build energy storage in the year 2024. On the other hand, it is anticipated that the next eight years will witness $44 billion investment in storage as compared to $3.9 trillion in power-generation capacity.

Currently, batteries are primarily used for energy storage but many experts opine that their designs are ill-equipped for storing large amounts of energy required for industries and communities, especially for the intermittent loss in renewable generation. There is scepticism amongst experts on long-term, grid-scale energy storage for averting any blackouts as the global share of renewable energy grows.

However, countries continue to aggressively support their deployment. For example, the UK launched a $1.3 billion fund targeting batteries amongst other innovation areas. Companies have jumped onto the bandwagon for catering to the demands of the growing renewable energy across the world. Mercedes Benz, a leading automotive player globally, is not only looking at electric vehicles but is looking at energy storage systems to be deployed across UK homes.

US-headquartered solar power developer 8minutenergy Renewables recently announced a 1 GW project pipeline in the energy storage space. The company has offices in the US, Singapore, and India indicating that it would be testing out multiple geographies for its ambitious plans.

Some researchers are also attempting to incorporate super-capacitors, a type of next-generation energy storage which may replace rechargeable batteries in high-tech devices, such as cell phones and electric vehicles. It needs to be understood that electrification systems in future will need to be disruption proof, considering the massive technological overhaul and upgrade taking place in cities globally.

Need for Storage

It should be remembered that over 1.2 billion people do not have access to electricity globally. Governments and financial institutions are looking to ensure that renewable energy and energy storage–powered mini grids may be a chance to provide affordable and continuous electricity.

For a long time, use of fossil fuels that have had an impact on the environment, including the emissions caused, have been criticized. The ambition to bring reliable electricity to over a billion plus people will need a cost-effective and long-duration storage. Since a centralized grid cannot provide electricity service to the chunk of the underserved population, distributed and remote power systems have a large potential for providing service around the world.

A key reason why this may see light of the day faster as compared to earlier times is the Paris Agreement, signed by leaders from over 197 countries in 2015. The agreement saw consent from all on reducing their emission levels with the aim of limiting global warming to less than 2°C compared to pre-industrial levels. This would be accompanied by a set of targets for emission mitigation in individual countries. The International Energy Agency estimates that over $13.5 trillion will be needed as additional investments for achieving these goals. This is both a challenge as well as an opportunity-driven scenario for players and financial institutions to not only make a difference but also make money in return.

Key Storage Technologies

Some of the common storage technologies include mechanical systems, such as flywheels, compressed air, or pumped hydro; electrochemical storage, such as lithium-ion (li-on) and flow battery technology.

» **Flywheel energy storage:** This kind of technology works by giving acceleration to a motor at a high speed and maintaining the energy as rotational energy. Such technology has been used in Switzerland and Belgium in the past but attempts are being made now to make them smaller, lighter, and cheaper. The application of flywheels has been tested in automobiles and rail vehicles, amongst others. Considering the maintenance cost is less than half of a UPS and only a change of bearings is needed every few years, they are indeed a source comparable to a battery. Another advantage is that they are less harmful to the environment as compared to electric batteries. Their ease and speed of generating power is the reason for them being explored across the world. Typically, grid balancing entails frequency and voltage control and a quality device can give real power resulting in renewable energy

sources. This is why they are ideal for variable power generated by solar or wind farms and stabilizing voltage at the local level. This is already being explored by a storage company called STORNETIC, which is partnering with renewable developer EDF, for a joint pilot project in France that will assess the performance of such technology. Besides this, pilot projects are also being tried in Australia, Canada, and the Philippines to name a few. It is also anticipated that flywheel storage market is expected to reach almost $500 million by 2024.

» **Compressed air energy storage:** This is akin to a pumped hydro power plant but has compressed ambient air stored under pressure in an underground cavern. When electricity is needed, the pressurized air is heated and expanded in a turbine that drives a generator for producing power. When electricity is required, the pressurized air is heated and expanded in an expansion turbine driving a generator for power production. Currently, only a handful of locations in Germany and the US have such plants and only some are being envisaged for the future. This technology's inherent advantage lies in the fact that it provides long-duration energy storage solution. Recently, NTStor, a company in Ontario, Canada, announced setting up one such project which would be able to cater to power 1,000 homes for 4 hours with 1.75 MW. There is also LightSail's Regenerative Air Energy Storage (RAES) units, which are being deployed at a half-megawatt scale in California, Hawaii, Canada, and the Caribbean before 20 MW units are rolled out later this year. In addition, Chinese scientists are exploring this for wind farms that see intermittent generation since China is already the largest renewable market in the world. The world's first-integrated storage system to be used was the Liverpool Wind Energy Storage Project (LWES) set up in Nova Scotia, Canada, which became the world's first wind energy project coupled with compressed air storage.

» **Flow battery:** This type of rechargeable battery incorporates rechargeability given by two chemical components dissolved in liquids in the system and only separated by membrane. There are some similarities between this technology and a fuel cell as well as battery, where it is the liquid energy that is tapped for creating electricity. The advantage of such a system is that they can be charged instantly by replacing the electrolyte liquid. A number of such types of batteries have been developed. In fact, since Lithium-ion is the most common technology, flow-battery technology is gradually picking up pace due to the inherent disadvantages of Lithium-ion being discharged quickly. In fact, such

batteries can typically absorb 10,000 charge and discharge cycles. It is steadily gaining ground in advanced countries for now, including the UK, US, and Australia amongst others.

» **Li-Ion technologies:** These batteries have been in use since 1991 when Sony started using it first. While they were initially meant for consumers, a large number of companies are looking at their use for energy-storage applications. In fact, the evolution of electric vehicles and their popularity is expected to give a spur to their demand and may witness similar popularity as petroleum in the late twentieth century. Their distinct advantage has been the range of uses. Tesla, the company looking to produce mass-scale electric vehicles and whose innovations are being watched with bated breath, is already setting up a factory to cater to large-scale demand for its vehicles as well as energy-storage solutions. Tesla may also set up a 100-MW hour power battery storage capacity in South Australia, which would be the world's largest utility-scale power storage and will boost renewable energy.

Their proven success in field installations has been the primary reason for their continued and increasing popularity. Additionally, their prices have fallen by almost 70% from an estimated $810—from $1,000/kWh to about $190/kWh since 2010. The lower levellized cost of storage makes them popular and while other technologies gain ground, Lithium-ion will continue to rule the roost in the near future. Other technologies, such as flow batteries, will need to display proven success for grid utilities in order to become a strong competitor.

It should be remembered that in every evolution, there is a technology that appeals to a large number of stakeholders. However, research and development is being carried out to make viable and convenient usage of other technologies.

Where India Stands

Closer home, India's stupendous renewable growth has drawn international investors and is expected to be a game-changer for a country, especially when the world's fastest-growing economy's one-fourth population lacks access to reliable electricity. The ambitious agenda of setting up 175 GW of solar and wind power plants in the country by 2022 has spurred the government, project developers, and investors into action. The recent announcement of electric vehicles to be used by government officials and the call to ramp up the sales of such vehicles *en masse* are reasons that will drive faster renewable energy generation. From the unorthodox, odd–even rule to the more acceptable ban on heavy-diesel vehicles, many policy measures have

been taken to cut down air pollution but the abundance of fossil fuel-based vehicles in India remains a major pollutant.

The next big step is expected to be the National Electric Mobility Mission Plan, which envisages sale of 6 million electric/hybrid vehicles by 2020 but little progress has been made since its announcement in 2013. With the sales being less than 1,000 in 2015/16 and a miniscule market share of 0.1% of the global share, a lot will need to be done.

Furthermore, India's grid infrastructure will take some time to be established. Since renewable energy is yet to become a strong and reliable source of power, in situations where sun or wind energy is not available, appropriate storage systems are required to ensure reliable electricity to consumers. The need for storage is increasingly being seen as critical considering the rapid renewable energy penetration as instances have been noticed where excess energy supply has been noticed.

Batteries are evolving and there have been some improvements in efficiency and cost reduction helping in larger adoption. Currently, India is behind its global counterparts on the energy-storage technologies and does not have any concrete policies in place vis-à-vis renewable plant deployments. Although a piecemeal approach has been adopted to discuss this at forums, there has to be a more concrete discussion on this front. One of the possible ways to have this pushed to the forefront will be through corporates, think tanks, and experts providing suggestions on this. For long-term players in the sector, the ability to provide integrated technology, generating, and storing power will hold them in good stead. It needs to be understood that a quarter of India's population lacks access to reliable electricity; also the growth in electric vehicles will push the need for greater renewable installations. Both the scenarios are inevitable in India's journey to reduce fossil fuel imports and maintain a GDP growth of 7%–8%.

India is assessing various storage alternatives to transform the transportation sector where lead-acid batteries are a prevalent technology. Electric vehicle technology has rapidly evolved over the past five years and has witnessed dramatic decline in cost of about 65%. Low-cost models, such as Nissan Leaf, Chevy Volt, Tesla, are making their ways to disrupt the automobile sector. The USA and China have lion's share of about 70% of electric vehicle market. India through its new electric vehicle policy has ambitious plans to completely electrify its automobile sector by 2030.

There are ideas being mooted to have electric vehicles with a plug-and-play system where discharged batteries on a lease/rent basis can be swapped with a recharged battery taking not more than

2.5–10 minutes for a four-wheel sedan to large buses. The need for adequate charging stations will lead to a bigger market creation for battery technologies.

To achieve this, however, the government will need to incentivize and provide tax breaks similar to initial stages of wind sector. The operational barriers also need to be assessed and addressed for example, setting up of large-scale battery producing units, transportation of the batteries to the retail /service centres, local electric vehicle manufacturing capabilities, and safety features, which requires a critical analysis to avoid the electric vehicle policy from collapsing.

Recent Developments

Recently, the start-up ION Energy, specializing in making infrastructure for enabling adoption of electric vehicles in India, raised funding from a clutch of investors signalling the big revolution expected in the niche segment. It is also estimated that that India's market of lithium-ion battery in India is projected to grow at a CAGR of over 32% during 2016–21.

An encouraging trend is seen in the country's public sector transmission company, Power Grid, that has given a contract to ViZn Energy Systems, a provider of energy storage systems for utility and micro grid applications, for a 1 MWh utility energy storage to ensure electrical grid stability in India. In fact, another big government organization, Indian Space Research Organisation, is also developing lithium-ion batteries that can result in a technology transfer for large-scale production soon.

In January 2017, India launched its first grid-scale battery storage system, which witnessed commissioning and operations on a 10 MW energy storage array by Tata Power Delhi Distribution jointly with Mitsubishi and the US energy storage company AES. Besides this, rechargeable battery and electric transport company BYD will collaborate with Canada-based renewables firm, SkyPower, to bid for energy storage projects in India. Additionally, Sydney-based lead-acid energy storage specialist, Ecoult, secured funding for developing and commercializing UltraBattery products, which would aid in expanding to international markets, such as India, where it signed a global manufacturing deal with India's largest battery manufacturer, Exide Industries. This is a step towards helping integrate renewable energy into grids.

Experts in Bloomberg New Energy Finance estimate that 800 MW of storage may be commissioned by India in the next three years. While this may be considered paltry as compared to the installations, it will give a fillip to a nascent sector and may encourage international players and technologies as was the case with solar some years back.

In fact, the Delhi-based Council on Energy, Environment, and Water (CEEW)