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ENERGY FUTURE

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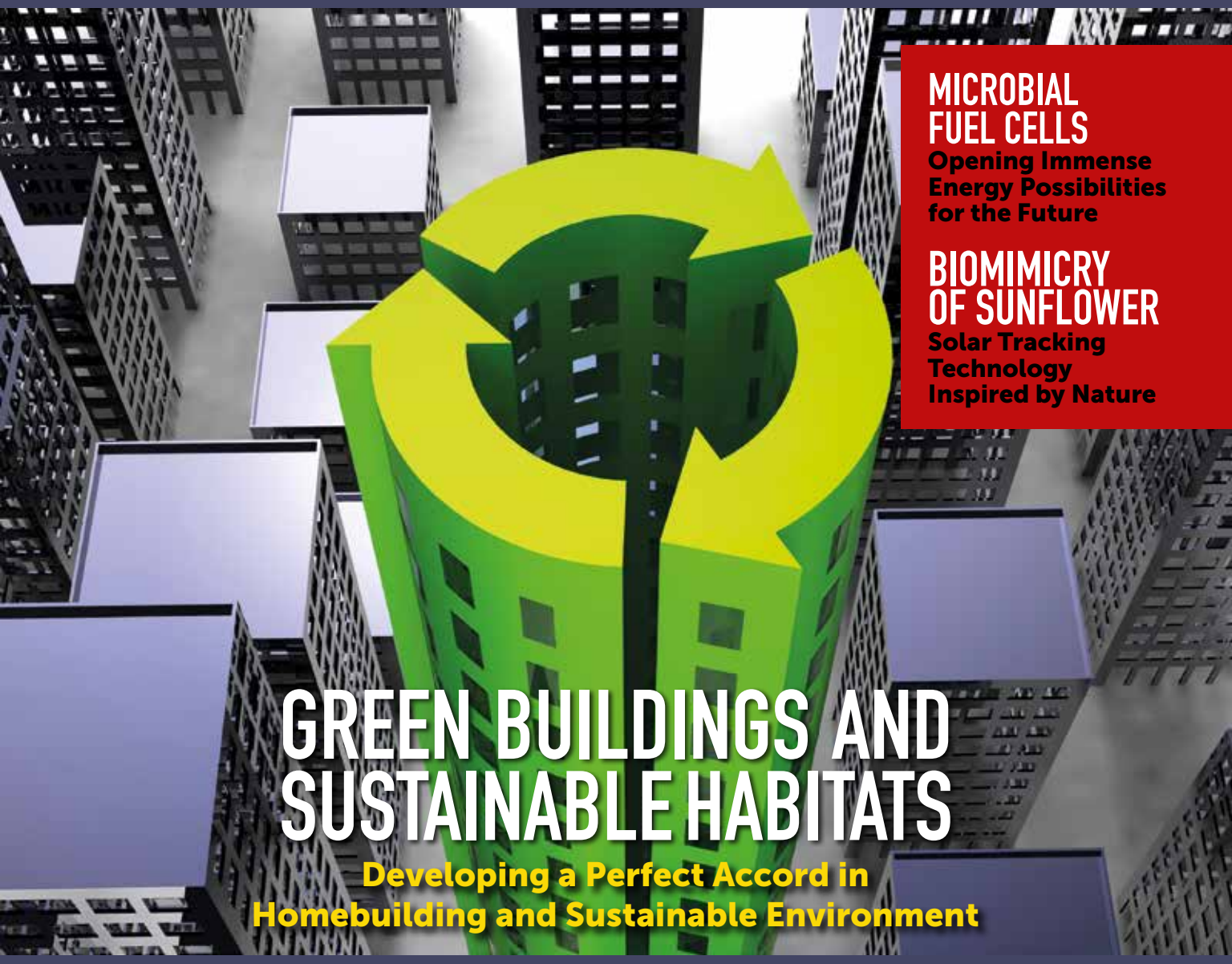

MICROBIAL FUEL CELLS
Opening Immense Energy Possibilities for the Future

BIOMIMICRY OF SUNFLOWER
Solar Tracking Technology Inspired by Nature

GREEN BUILDINGS AND SUSTAINABLE HABITATS
Developing a Perfect Accord in Homebuilding and Sustainable Environment

VIEWPOINT
Corey Enck
LEED AP | Vice President | LEED Technical Development

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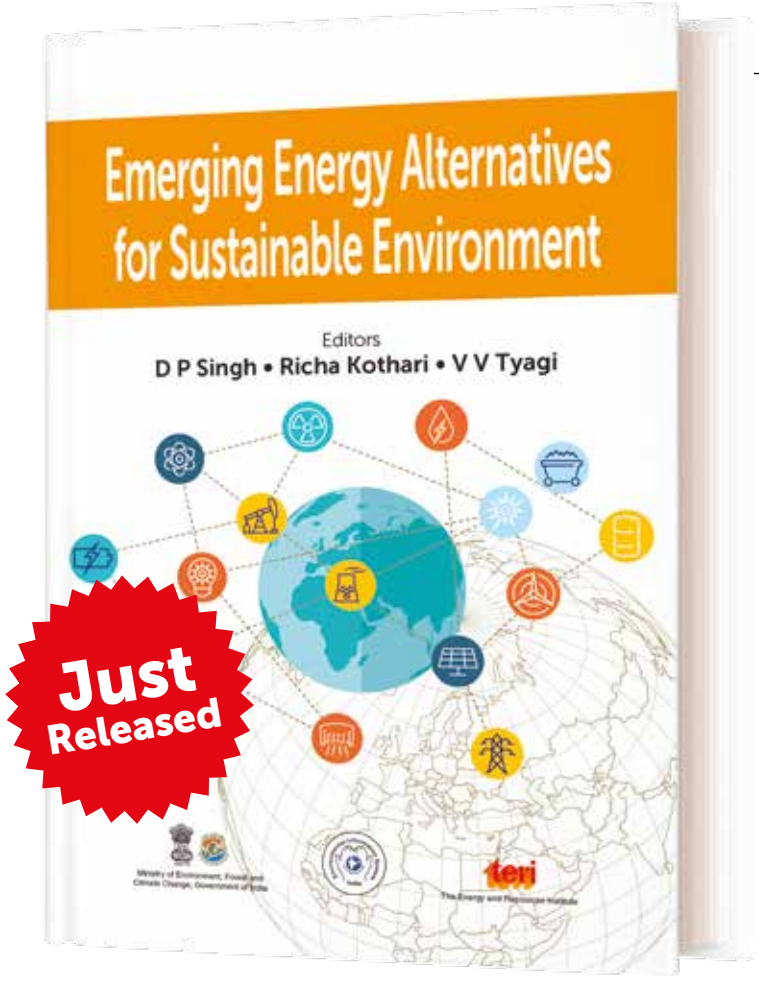
"Sustainable technologies—the only hope for human survival"



Major topics covered

- Renewable energy sources and recent advances
- Emerging green technologies for sustainable development
- Solid waste management and its potential for energy generation
- Solar energy applications, storage system, and heat transfer
- Hydrogen energy: present and future

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This latest TERI publication aims to address the role of sustainable technologies in energy generation options for clean environment. Emerging Energy Alternatives for Sustainable Environment covers a wide spectrum of energy generation approaches. It provides essential and comprehensive knowledge on green energy technologies that will be useful for engineers, technocrats, and researchers working in this field.

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From the editor's desk...

According to Wikipedia, 'a sustainable habitat is an ecosystem that produces food and shelter for people and other organisms, without resource depletion and in such a way that no external waste is produced'. If we were to move towards cities and towns that are self-sustainable in a broader sense, a paradigm shift is required not only in buildings' design but at the urban planning itself. But, let us not forget the looming threat due to climate change. As per the United Nations Environment Programme (UNEP), 'Buildings and construction sectors account for 40 per cent of global energy use, 30 per cent of energy-related greenhouse gas (GHG) emissions, approximately 12 per cent of water use, nearly 40 per cent of waste…'. It further states that 'two billion additional urban inhabitants are expected by 2030, the majority of whom will be in the rapidly growing cities of Africa, Asia, and Latin America.' Coalescing all these together clearly predicates that the present approach to urban planning and building design has to change. Interestingly, it is increasingly being realized that many of the traditional practices were much more sustainable than the modern ones. On the other hand, the innovation in technologies, materials, and construction practices can contribute significantly in making cities, and buildings therein, more resource efficient and 'climate adaptable'.

But optimally designed and constructed habitats are only one side of the coin. Equally important factor affecting sustainability is the 'how' part that is the utilization and consumption. A very well designed building with very profligate living would not lead to the desired outcomes. The lifestyle choices that one makes have long-term implications. That means that for our habitat to be truly sustainable, the focus must also be put on sustainable consumption and production. This is especially critical for the developing economies where rising incomes bring in more wasteful tendencies. In other words, sustainable habitats necessarily require very fine balancing of a myriad of elements. Undoubtedly, energy future is all about inter-dependability and well-orchestrated resources.

Amit Kumar

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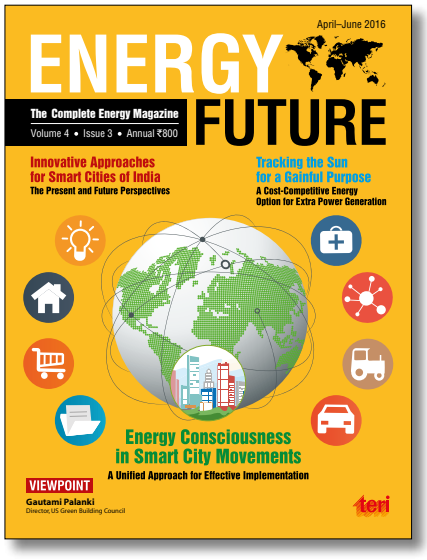

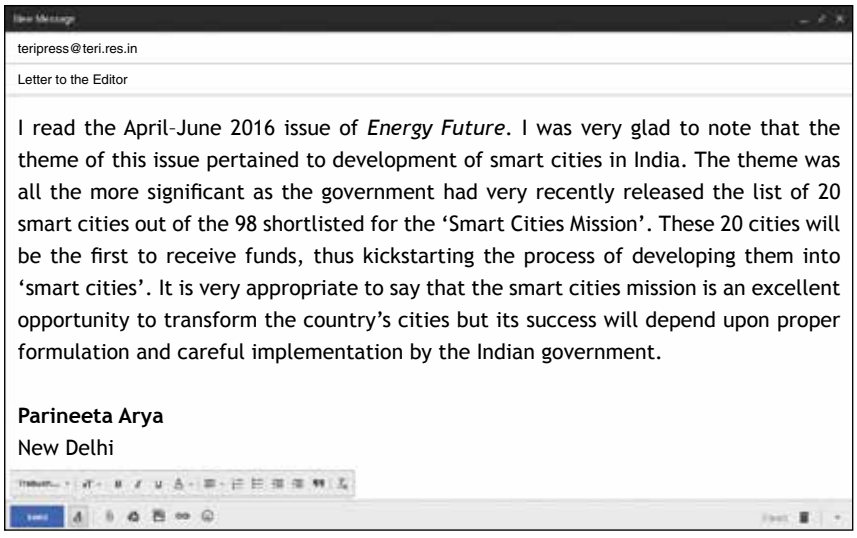

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Letter to the Editor

I read the April-June 2016 issue of *Energy Future*. I was very glad to note that the theme of this issue pertained to development of smart cities in India. The theme was all the more significant as the government had very recently released the list of 20 smart cities out of the 98 shortlisted for the 'Smart Cities Mission'. These 20 cities will be the first to receive funds, thus kickstarting the process of developing them into 'smart cities'. It is very appropriate to say that the smart cities mission is an excellent opportunity to transform the country's cities but its success will depend upon proper formulation and careful implementation by the Indian government.

Parineeta Arya
New Delhi

"The article, 'Tracking the Sun for a Gainful Purpose', published in the Solar Quarterly section of your esteemed magazine is very informative. It is indeed a very useful concept that could help the solar industry maximize the solar potential. Global warming has increased the demand and request for green energy produced by renewable sources such as solar power. Consequently, solar tracking is increasingly being applied as a sustainable power generating solution. It is rightly said by the author that the need of the hour is to track for a gainful purpose of extra power generation, wherever feasible. Also, it has been correctly pointed out that solar PV technology and associated programmes are in a stage of continuous evolution, and solar tracking is not an exception."

Tanvir Alam
Hyderabad

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

Email: teripress@teri.res.in

Editor
Energy Future

"The article on the future of renewable energy (published in the Energy Insights section) makes for an interesting reading. No doubt that after the Paris Agreement there is a discernible global trend towards less reliance on fossil fuels, prevention of climate change, and efforts to create a sustainable society. Also, new entrants from the utility, non-utility, and residential sectors are bound to change the landscape of investment, electricity production, transmission, and consumption. The success story article also highlights that the Indian government is largely promoting mega solar energy programmes in the country. It would therefore not wrong to say that the future belongs to renewable energy and the energy landscape of the world is destined to undergo a vast transformation."

Pooja Kohli
Mumbai, Maharashtra

"It was nice to read about the 7th GRIHA Summit report covered under the Special Event section. I came to know about the GRIHA rating system through one of my friends who is employed at one of the green buildings certified by GRIHA. I also liked reading about the generation of green power and manure from surplus crop residues. The technology for conversion of crop residues into methane-rich biogas should really be encouraged as a practice in sustainable agriculture. All the articles on smart cities development have also been appropriately written by the respective authors to not only enlighten the professionals working in the energy sector but also the general masses."

Dr Ramvats Sharma
Ambala, Haryana

CONTENTS

'WORLD'S LARGEST' ROOFTOP SOLAR PLANT OPENS IN BEAS

An 11.5 MW rooftop solar energy plant, touted to be the largest of its kind in the world, has been inaugurated by the Chief Minister of Punjab Shri Prakash Singh Badal in Beas near Amritsar. Spread in an area of over 82 acres and nearly 45 km away from Amritsar, the solar plant has been built at a cost of ₹139 crore by the Radha Soami Satsang Beas (RSSB). It will generate nearly 150 lakh units annually and is expected to offset 19,000 tonnes of carbon emissions annually. With this, the ₹139-crore solar energy plant here has become country's largest, with solar panels spread over 82 acres on eight rooftops of sheds and a capacity to generate 19.5 MW. The project will generate 27 million units of electricity per annum, enough to cater to the electricity needs of approximately 8,000 households. The Chief Minister lauded the sect management for setting up the solar plant, while the state's renewable energy minister Shri Bikram Singh Majithia said the Punjab government was focussing on setting up solar energy plants across the state. Shri Badal extoled the Punjab Energy Development Agency (PEDA) for ushering in a solar-power revolution in the state. Badal said the state-of-the-art project set up by the Radha Soami Satsang Beas Educational and Environmental Society (RSSBEES) in technical collaboration with PEDA will go a long way in motivating other states to replicate such projects to generate clean and green energy. EF

Source: www.hindustantimes.com

SHRI PIYUSH GOYAL LAUNCHES THE 'SURYA MITRA' MOBILE APP

The first National Workshop on Rooftop Solar Power was held at Vigyan Bhawan in New Delhi on June 7, 2016. While addressing on this occasion, Shri Piyush Goyal, Minister of State (IC) for Power, Coal and New & Renewable Energy said that efforts and commitment of all stakeholders made renewable energy (RE) targets achievable. The Minister Shri Goyal launched a mobile app called 'Surya Mitra' App at the event.

The GPS-based mobile app has been developed by the National Institute of Solar Energy (NISE), which is an autonomous institution of MNRE. The Surya Mitra Mobile App is currently available in Google Play Store, which can be downloaded and used across India. This App is a high end technology platform which can handle thousands of calls simultaneously and can efficiently monitor all visits of Suryamitras. The trained Suryamitras who opt for entrepreneurship have joined in the Mobile App in several states. This innovative mobile approach shall enhance the employment of trained youth in solar PV technology and also improve the businesses of solar entrepreneurs because quality servicing, maintenance, and repairing professionals are now available to customers at the click of a button on their mobiles. EF

Source: www.pib.nic.in

SANKHYA BECOMES WORLD'S FIRST LEED PLATINUM CERTIFIED DATA CENTRE

The ITC Sankhya Data Centre in Bengaluru has been awarded a LEED platinum certification in the 'Data Centre' category by the US Green Building Council (USGBC). Located in Cox Town, the centre is the first in the world to receive the certification after the category was established in 2013. Sankhya is the primary data centre for all operations of the Kolkata-headquartered company. It is a four-storeyed building measuring a total of 30,000 square feet and occupying a footprint of 7,500 square feet. It began operations in February 2015.

Data centres in hotels are high energy guzzlers, given the large equipment and servers they use. Given the increasing importance laid on environment-friendly construction and operations, controlling energy consumption at these centres is becoming a focus point for organizations. Sankhya is completely powered by renewable energy. The building is designed to provide cooling power to its servers. It also closely monitors water use. Mahesh Ramanujam, Chief Operating Officer of USGBC, said, "LEED is the premier global rating system for making sure that buildings are designed, constructed and operated so that they save energy, water and precious resources, reduce waste and carbon emissions, and provide healthier environments for the people who use these buildings every day." EF

Source: economictimes.indiatimes.com

INDIA'S FIRST CELLULOSIC ALCOHOL TECHNOLOGY DEMONSTRATION PLANT INAUGURATED

Union Minister for Science and Technology and Earth Sciences, Dr Harsh Vardhan, inaugurated India's first second-generation (2G)ethanol plant at Kashipur in Uttarakhand. Taking pride in the indigenously-developed technology and its evolution into a demonstration plant, he said that more such examples are needed, for the initiatives, such as 'Make in India' and 'Swachh Bharat Abhiyan' to be truly successful. Such technological breakthroughs can make India stand out as a leader in the world's struggle to save the earth from challenges of global warming, he noted.

The Minister said that it is a novel technology suited to both Indian and global needs and is projected to be capable of converting all types of agricultural residues, such as bagasse, rice straw, wheat straw, bamboo, cotton stalk, corn stover, wood chips, etc., to ethanol in less than 24 hours, with optimum product yields. If successfully operated and scaled-up, it will establish India as a major global technology provider in the arena of renewables and reduction in carbon-emissions, besides effecting considerable savings in import of crude oil.

The Technology Demonstration plant, with a capacity to consume 10 tonnes of biomass per day, is based on the globally-competitive indigenous technology of converting lignocellulosic biomass to ethanol. It is a feedstock-independent technology developed by DBT-ICT Centre for Energy Biosciences at the Institute of Chemical Technology (ICT) Mumbai, supported by the Department of Biotechnology, Ministry of Science and Technology and the Biotechnology Industry Research Assistance Council (BIRAC). EF

Source: www.pib.nic.in

ASHDEN INTERNATIONAL AWARD FOR ORGANIZATIONS PIONEERING SUSTAINABLE ENERGY IN INDIA

Two clean energy organizations (Frontier Markets and Greenlight Planet) operating in India have both won a 2016 Ashden International Award—the world's most prestigious green awards. The Ashden Awards are a globally recognized measure of excellence in the field of sustainable energy and each winner receives up to £30,000 prize money as well as tailored business support to scale up their work.

'Frontier Markets' offers a unique distribution model to provide high quality solar lamps and other solar systems to hard-to-reach villages in India, using a network of trained women called Solar *Sahelis*. To date, 'Frontier Markets' has sold over 100,000 clean energy products in Rajasthan and wins the Ashden Award for Clean Energy for Women and Girls, supported by UK Aid.

'Greenlight Planet' has till date sold over five million quality solar products across the world. It carefully screens and selects strategic partners who can distribute them out to the most remote regions and overcome final barriers to purchase such affordability for the poorest consumers. 'Greenlight Planet' wins the Ashden Award for Increasing Energy Access, supported by the IKEA Foundation. EF

Source: www.ashden.org

BHEL COMMISSIONS SUPERCRITICAL PLANT IN MAHARASHTRA

Bharat Heavy Electricals Limited (BHEL) has achieved another landmark by successfully commissioning a 660 MW supercritical thermal unit in Maharashtra. The unit has been commissioned at Mouda Super Thermal Power Station (STPS) at Mouda in Nagpur district of Maharashtra. The order for setting up two coal-based thermal units of 660 MW was placed on BHEL by NTPC Ltd.

While the first unit has been commissioned, work on the other 660 MW unit is also in an advanced stage. Notably, BHEL had earlier set up two units of 500 MW each at Mouda STPS, which are in operation. In the supercritical segment, BHEL has successfully demonstrated its leadership status and technological capability in the manufacture and execution of 660 MW, 700 MW, and 800 MW sets. Notably, the unit commissioned by BHEL at Mouda, is the first to be commissioned out of the 11 units ordered under bulk tendering to different manufacturers. BHEL has a long-standing partnership with NTPC and has supplied over 30,000 MW of the coal-based power plants of NTPC and its JVs that account for around 80 per cent of their coal-based installed capacity. Significantly, in the FY 2015–16, all the 2,255 MW projects of NTPC and its JVs were executed by BHEL. BHEL has also been a major partner in the development of Maharashtra's power sector. BHEL has supplied and executed more than 16,000 MW of sets in the state so far. EF

Source: economictimes.indiatimes.com

THE WORLD BANK APPROVES $625-MILLION AID FOR INDIA'S SOLAR PROGRAMME

The World Bank's Board has approved $625 million loan to support India's grid connected rooftop solar programme to generate clean energy. The Board also approved a co-financing loan of $120 million on concessional terms and a $5 million grant from Climate Investment Fund's (CIF) Clean Technology Fund. "The project will finance the installation of at least 400 MW of grid connected rooftop solar photovoltaic (GRPV) across India," the World Bank said in a statement. These solar PV installations, it said, will provide clean, renewable energy, and reduce greenhouse gas (GHG) emissions by displacing thermal generation. The project will also strengthen the capacity of key institutions, and support the development of the overall solar PV market.

It will be implemented by the State Bank of India, which will on-lend funds to solar PV developers/aggregators and end-users, who wish to invest in mainly commercial and industrial rooftop PV systems. "India is endowed with huge solar energy potential, and the World Bank is strongly supportive of the government's plans to harness this potential and increase India's solar PV capacity to 100 GW. This project will support this target, by providing financing to some of the 40 GW of solar PV which will be placed on rooftops," said Onno Rühl, World Bank Country Director in India. EF

Source: economictimes.indiatimes.com

INDIAN RAILWAYS TO MEET 10 PER CENT OF ENERGY NEEDS VIA RENEWABLES BY 2020

Indian Railways, which has envisioned a plan to generate 1,000 MW of solar energy by 2020, claims to be on track to become the largest harvester of rooftop solar plants, and plans to meet 10 per cent of its total energy requirements through renewable energy by 2020. As part of its 'Solar Mission', the transporter plans to generate 500 MW of solar energy through rooftop solar panels and the rest 500 MW through land-mounted solar panels. It also aims at generating 312 MW of energy through windmill plants with the help of Railway Energy Management Corporation Limited. Sources in the Railway Ministry said Indian Railways has already tied up with the Solar Energy Corporation of India (SECI) to generate 100 MW of solar energy through land-mounted solar plants and production is estimated to commence from December 2017, at an average rate of ₹4.50 unit. The transporter has also tied up with Rewa Ultra Mega Solar (RUMS) to generate 50 MW of solar energy through land-mounted solar plants at an average rate of ₹4.50 per unit and the production is estimated to commence from December 2017.

"We have been focussing on solar energy in a big way. As more and more of our network gets electrified and the use of EMU trains increases, our energy demand will also increase. It is of paramount importance that we start focussing on renewable energy; not only will it reduce our carbon footprint, it will also help us meet 10 per cent of our total energy requirement by 2020," a senior railway official said. EF

Source: www.financialexpress.com

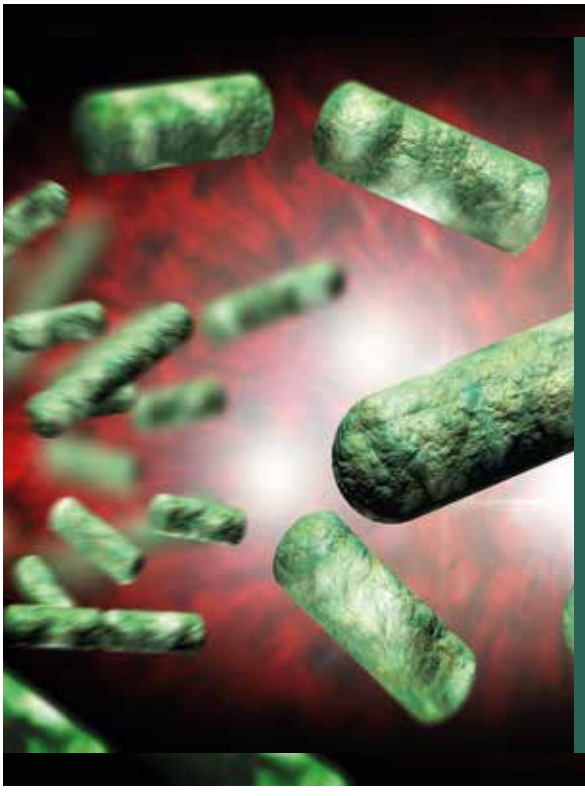
IRON-BASED DYES TO REDUCE SOLAR CELL COSTS DRASTICALLY

Researchers at Lund University in Sweden have successfully developed a system that can use iron-based dyes in solar cells. It will drastically reduce costs of these cells and bring down the cost of generation. "The new findings will accelerate development of inexpensive and environment-friendly solar cells. The goal is to be able to use iron-based dyes in solar cells in the future. By using iron instead of other more expensive and rare metals, the production of solar cells and light catchers will become cheaper and more environment-friendly. The demand for solar cells is therefore expected to significantly increase", said the university in a statement.

At present, solar cells are made from Ruthenium dyes to capture sunlight. But, it is 100 million times less common than iron and hence the high cost. "In this new study, we explain how iron-based dyes work on a molecular level. That way we are able to further improve these iron complexes so that they become even better at absorbing and storing solar energy", said senior lecturer Petter Persson. EF

Source: economictimes.indiatimes.com

BERKELEY LAB SCIENTISTS CREATE JET BIOFUEL USING E.COLI



Researchers at the US Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) have engineered a strain of bacteria that enables a 'one-pot' method for producing advanced biofuels from a slurry of pre-treated plant material. The *Escherichia* coli (*E. coli*) is able to tolerate the liquid salt used to break apart plant biomass into sugary polymers. Because the salt solvent, known as ionic liquids, interferes with later stages in biofuels' production, it needs to be removed before proceeding, a process that takes time and money. Developing ionic-liquid-tolerant bacteria eliminates the need to wash away the residual ionic liquid.

The achievement, described in a study published in the journal *Green Chemistry*, could be a critical step in making biofuels a viable competitor to fossil fuels by helping to streamline the production process. "Being able to put everything together at one point, walk away, come back, and then get your fuel, is a necessary step in moving forward with a biofuel economy. The *E. coli* we have developed gets us closer to that goal. It is like a chassis that we build other things onto, like the chassis of a car. It can be used to integrate multiple recent technologies to convert a renewable carbon source like switchgrass to an advanced jet fuel" said the study's Principal Investigator Aindrila Mukhopadhyay. EF

Source: www.renewableenergyfocus.com

SIERRA LEONE SIGNS ENERGY AGREEMENT WITH UK

Sierra Leone has become the first country participating in the UK's Energy Africa campaign to sign an agreement to ensure power for all citizens of Sierra Leone by 2025. The Government of Sierra Leone will eliminate tax on qualified internationally certified renewable energy products to ensure modern power to one million people by 2020.

The signing between the UK and Government of Sierra Leone took place during the country's first decentralized renewable energy conference at Bintumani Conference Centre. The Energy Revolution event was hosted by Sierra Leone's Ministry of Energy and the UK's Department for International Development (DFID). The one-day event, organized by global development experts Adam Smith International, is the launch of a series of renewable energy initiatives to eradicate energy poverty in Sierra Leone. The Government aims to deliver off-grid technology and solar home systems to its population, where currently less than 1 per cent has access to power in rural areas. Sierra Leone is one of the ten African nations that have joined the UK's Energy Africa campaign to expedite universal energy access to lift millions out of poverty and end dependency on aid. EF

Source: www.renewableenergyfocus.com

CARLO RATTI ASSOCIATI UNVEILS ENERGY EFFICIENT NEW DESIGN FOR OFFICE SPACE

International design and innovation firm Carlo Ratti Associati has developed a personalized heating, cooling, and lighting system which follows occupants as they move around the building, like an individually-tailored environmental bubble. The new system—part of the redesign of the Agnelli Foundation headquarters in Torino, Italy—gives shape to a workplace that naturally learns and is synchronized to its users' needs, thus optimizing space usage and limiting energy waste. Designers and researchers at Carlo Ratti Associati equipped the century-old structure in the city center of Torino, Italy, with Internet-of-Things (IoT) sensors that monitor different sets of data, including occupancy levels, temperature, CO_2 concentration, and the status of meeting rooms. Based on this information, the building management system (BMS) responds dynamically, adjusting lighting, heating, air-conditioning, and room booking in real-time. Once building occupants set their preferred temperature via a smartphone app, a thermal bubble follows them throughout the building, as the fan coil units, situated in the false ceilings, are activated by human presence. When an occupant leaves a given space, the room returns naturally to 'standby mode' and saves energy—just like a computer does. EF

Source: pr@carloratti.com

LONDON BOROUGH INSTALLS 6,000 SOLAR PANELS OVER MARKETPLACE

A London council is unveiling a vast installation of 6,000 solar panels on a wholesale market rooftop, which it says is the largest such array put up by a local authority. The London Borough of Hounslow says its £2m investment in solar, which has been installed on the roof of Western International Market, is also the first by a council to adopt battery storage to maximize the power from the panels. The 1.73 MW array of 6,069 panels and four 60 kW lithium batteries system now generates half the site's required electricity. The site is west London's largest wholesale market for fresh produce and flowers, and uses around 3.5 MWh of electricity to provide climate controlled facilities to around 80 wholesalers and buyers—the equivalent of 1,750 homes a year. The solar system will contribute 2 per cent of its carbon reduction target, cutting emissions by more than 780 tonnes a year. It will also save £148,000 in energy costs which, along with £100,000 in generation tariff payments and £7,000 in export tariffs, means that the council expects to be £255,000 better off in the first year of operation. LG Electronics, one of Hounslow's partners in the scheme, said it was the company's largest solar panel installation in Europe and would deliver significant costs savings to the borough. EF

Source: www.theguardian.com

INDIA RANKS THIRD IN 'RENEWABLE ENERGY COUNTRY ATTRACTIVENESS INDEX'

India's renewable energy sector has been ranked third in the Renewable Energy Country Attractiveness Index (RECAI) with China at second, and the USA on top. The so-called emerging markets now represent half the countries in the 40-strong index, including four African markets featuring in the top 30.

While the top three countries maintained their ranking, Chile, Brazil, and Mexico climbed higher in the index to be ranked in the top 10 at the fourth, sixth, and seventh, respectively. Germany at fifth and France at eighth fell in the latest ranking.

India's high position is thanks to the strong focus of the government on renewable energy as well as timely implementation of renewable energy projects. The report also suggests that with the growing number of jurisdictions contracting utility-scale renewable energy through competitive auction processes, renewable energy is increasingly proving its mettle against conventional energy generation. Renewable energy auctions in India, South Africa, and Peru saw bids that fossil generators would struggle to match. The index ranks 40 markets on the attractiveness of their renewable energy investment and deployment opportunities, based on a number of macro, energy market, and technology-specific indicators. The methodology has been refreshed in the latest edition to reflect greater focus on energy imperative, policy stability, and routes to market. EF

Source: www.business-standard.com

JUWI STARTS BIGGEST OFF-GRID SOLAR PLANT AT AUSTRALIAN GOLD MINE

Juwi AG, a German renewable energy developer, started operations at what it said is the world's largest off-grid solar plant located at a gold and copper mine in Australia. Juwi's Australian unit built the 10.6-MW solar park at the DeGrussa mine about 560 miles (901 km) north of Perth for Sandfire Resources NL. The park's 34,000 solar modules are spread over 49 acres and linked to a 6-MW battery storage system. Together, they will supply daytime power for Degrussa.

A 19-MW diesel plant can take over the mine's power supply when the solar panels are not producing. The solar plant will reduce DeGrussa's CO_2 emissions by 12,000 tonnes annually and cut diesel consumption by 1.3 million gallons or 20 per cent. The project was financed by the Clean Energy Corporation, Neoen SAS and with a A$21 million ($15.7 million) grant from the Australian Renewable Energy Agency. EF

Source: www.renewableenergyworld.com

RENEWABLE ENERGY NOW SUPPLIES ALMOST A QUARTER OF THE WORLD'S POWER NEEDS

The year 2015 was an absolutely huge 12 months for renewable energy, with a new global status report on clean energy highlighting how 2015 was a record year for the industry—including the revelation that renewable energy can now satisfy nearly a quarter of the world's power demands.

According to energy policy network REN21, record clean energy investments in 2015 drove the largest annual increase ever in renewable power generating capacity, with an estimated 147 GW added to the global grid—suggesting that by the end of 2015, renewable capacity could shoulder 23.7 per cent of global electricity requirements. Among new investments in the renewable power sector, wind and solar represented the majority of growth, accounting for about 77 per cent of new installations, with hydropower taking up most of the rest. Jobs in renewable energy have increased, and now employ some 8.1 million people across the world. Overall, global investments in clean energy hit $285.9 billion, topping 2014's $273 billion—a year in which 19.2 per cent of the world's consumption of energy was provided by renewables.

China is driving this growth, accounting for more than one-third of global investments in renewable energy, with the US, India, Japan, and the UK, rounding out the top five nations. In terms of overall power capacity sourced from renewables, not including hydropower, China again leads, trailed by the US, Brazil, Germany, and Canada. But, if you look at the capacity of renewable power per capita, the field looks pretty different: Denmark leads, then Germany, Sweden, Spain, and Portugal. EF

Source: www.sciencealert.com

GREEN BUILDINGS AND SUSTAINABLE HABITATS

Developing a Perfect Accord in Homebuilding and Sustainable Environment

With deteriorating environment and rising pollution levels leading to global warming all over the world, the concept of 'green buildings' is emerging on the mainstream. The design, construction, maintenance, and operation of green buildings reinforce a sustainable environment, thereby impacting health and cleanliness of the human society in a harmonious way. In other words, green building design involves finding a balance between homebuilding and the sustainable environment. Green buildings are the combination of every aspect that fosters healthy and green lifestyle. In this article, **Sharada Balasubramanian** discusses about the energy efficiency aspects along with managing and monitoring energy use in green buildings. She also dwells on the use of green windows and architectural glass in zero-energy buildings and feels that for successful green building implementation in India, there must be proper funding, political willingness, and long-term vision from the government.

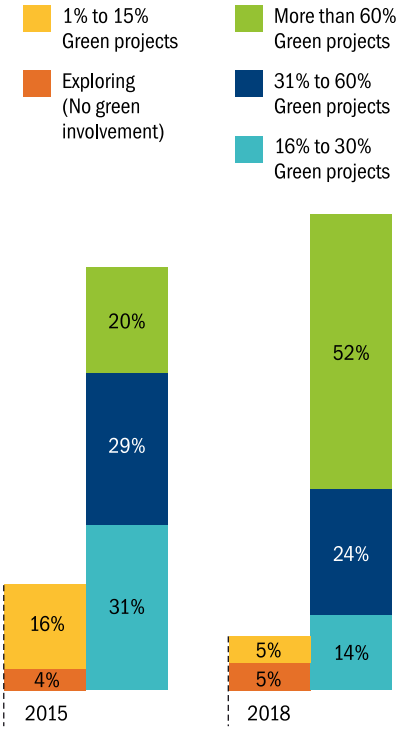


Figure 1: Levels of green building activity for respondents in India (2015 and expected 2018)
Source: Dodge Data and Analysis Report

A steep consumer demand has now pushed the global green building market to a trillion dollar industry. According to the latest report from the US-based Dodge Data & Analytics, by 2018, green buildings in India will grow by 20 per cent. The survey, which was done in almost 70 countries, shows that global green buildings continue to double every three years. Further, the report mentioned that green buildings save operational costs in comparison to conventional buildings. The survey respondents expect 14 per cent savings in operational costs over five years for new green buildings. Likewise, they expect 13 per cent savings in operational costs over five years for green retrofit (adding new features or changes in existing buildings) and renovation projects. The countries which responded to the survey also said that there is a 7 per cent increase in asset value of green buildings, in new or renovated as against conventional buildings.

India is among the countries with green activity above the global average of 24 per cent. The other countries in the list include South Africa, Singapore, Germany, and Mexico. Countries with the lowest percentage of respondents who expect to continue new green institutional projects are: Poland (15%), Mexico (25%), and India (26%). These are the countries which expect to build green commercial projects in future. Figure 1 shows levels of green building activity for respondents in India.

The survey done in India perceived lack of political support (35%) and lack of public awareness (48%) to be the obstacles to green buildings. Further, the report revealed that 51 per cent response for building green buildings is for 'creating a sense of community'. The study indicated that the top sector for green building growth globally is commercial construction, with nearly half (46%) of all respondents expecting to do a green commercial project in the next three years. New commercial construction is the top sector for expected green buildings in Mexico, Brazil, Colombia, Germany, Poland, Saudi Arabia, China, and India.

Are Our Buildings Energy-Efficient?

Buildings consume 40 per cent of energy and emit one-third of greenhouse gases (GHGs) globally. Along with this, there are increasing issues due to climate change. Therefore, energy efficiency in green buildings has to be a primary mandate among architects. Apart from the buildings that will be built, there needs to be a careful consideration on existing buildings, and how they can be made energy-efficient. Isn't it amazing that about two-thirds of buildings are yet to be built by 2030 in India! For these buildings, we need appropriate policies which will reduce the use of resources, such as energy, building materials

among other greening architectural elements. Let us take the example of the most common energy consumer in urban buildings—air conditioners. According to experts from the Centre for Science and Environment (CSE), currently the air conditioning area constitutes just 3 per cent of the built up area in New Delhi. However, if this mechanical cooling keeps increasing in an uncontrolled manner, it will be threatening the energy security in future.

In a growing economy like India, the demand for commercial, residential, and institutional space has increased rapidly, and this in turn, has led to building high comfort level structures that are resource-intensive. Further, demand for residential and commercial space will push carbon emissions to a higher level. The construction industry, which is growing at 10 per cent of the gross domestic product (GDP) in the last decade, is above the world average of 5.5 per cent per annum.

This economic expenditure will definitely have environmental impacts, in terms of energy, water, and other resources. Though there are environmental, social, and economic benefits associated with green buildings, the major barrier to construction of such buildings is lack of awareness. The higher compliance standards and its appropriate implementation can be found in developed countries like Germany. We need such measures in India as energy is one of the most critical issues in the building sector and for governments, consumers, and environmentalists today.

A typical building in India has the energy intensity of 250 kWh/m^2/year of energy. The official energy conservation building code for buildings expects to cut this to 140–170 kWh/m^2/year. It is believed that high performance buildings can achieve a target of even 75 kWh/m^2/year. India aims to reduce the emissions intensity of its GDP by 33–35 per cent by 2030 from 2005 levels for strengthening energy security, and to bring in climate-friendly growth. For achieving this, action will be set in the different sectors of construction industry.

For bringing in energy-efficiency in green buildings, various components, such as windows, doors, and use of materials have to be given serious consideration. These can save high energy costs. For this to happen, the right kind of architecture is needed.

Green Windows

In India, traditionally, wooden windows were used widely. Wood was then available in various shapes and sizes. However, today with environmental degradation and rapid deforestation, proponents of energy-efficient windows believe that wooden windows should now be replaced with unplasticized polyvinyl chloride (UPVC) windows. Though aluminium windows could have been another alternative, it is not considered energy-efficient.

UPVC windows are widely used globally, from the deserts of Arizona to the cold Scandinavia/Russia, from

IN INDIA, TRADITIONALLY, WOODEN WINDOWS WERE USED WIDELY. WOOD WAS THEN AVAILABLE IN VARIOUS SHAPES AND SIZES. HOWEVER, TODAY WITH ENVIRONMENTAL DEGRADATION AND RAPID DEFORESTATION, PROPONENTS OF ENERGY-EFFICIENT WINDOWS BELIEVE THAT WOODEN WINDOWS SHOULD NOW BE REPLACED WITH UNPLASTICIZED POLYVINYL CHLORIDE (UPVC) WINDOWS. THOUGH ALUMINIUM WINDOWS COULD HAVE BEEN ANOTHER ALTERNATIVE, IT IS NOT CONSIDERED ENERGY-EFFICIENT.

TODAY, THERE ARE WINDOWS WHICH HAVE INHERENT THERMAL INSULATION FEATURES, WHICH CAN BE ENHANCED WITH DOUBLE GLAZING, THUS REDUCING HEAT TRANSFER THROUGH THE WINDOWS. THIS LEADS TO IMPROVED THERMAL PERFORMANCE, HELPING HOMEOWNERS TO IMMEDIATELY LOWER HEATING/COOLING COSTS. WITH UP TO 40 PER CENT OF A HOME'S ENERGY FOR COOLING OR HEATING BEING LOST OR GAINED THROUGH WINDOWS, IMPROVING THEIR THERMAL PERFORMANCE IS NECESSARY TO REDUCE ENERGY COSTS AND INDIA'S GHG EMISSIONS. IT IS ALSO IMPERATIVE THAT GOVERNMENT STEPS IN TO REDUCE OR ELIMINATE THE USE OF WOODEN WINDOWS IN LARGE TOWNSHIPS, COMMERCIAL BUILDINGS, AND INSTITUTIONS.

the scorching Gulf to the tropics of Malaysia, Thailand, China, South Korea, and Taiwan, among other countries. In Europe and North America, only UPVC windows are used in their residential constructions as new materials and/or for replacement. Such windows conserve energy throughout their lifetime (from raw material stage to use stage), and are recognized as 'green windows', scoring over traditional wood and metal windows. Research indicates that in the US, energy star qualified windows lower power bills by almost 7–15 per cent.

In the US, the Department of Energy strongly encourages and recommends people to begin their energy efficiency process with insulation of windows. The Energy Star checklist recommends people to check their home for leaks, including heating and cooling ducts, doors, and cracks. This contributes significantly to energy losses that happen through windows. UPVC windows are best suited for weather conditions in India. One can use these windows from the coastal areas to coldest Ladakh, to heavy rains of Cherrapunji in Assam, to strong cyclonic winds of Odisha to hot deserts such as Thar in Rajasthan. They also provide sound and dust insulation, reducing noise to the extent of 20–30 decibels, making it ideal for using in schools, colleges, hospitals, community centres, etc. Some of their advantages are: (i) They are easy to install; (ii) They save energy; (iii) They are sound- and waterproof; (iv) They are long lasting; and (v) They involve less maintenance. They do not let outside heat in (and vice-versa in cold climate), providing comfort and saving heating/cooling energy to the tune of 20–25 per cent. While UPVC windows are used in the green buildings for better rating, some builders use these windows for energy efficiency, convenience, and comfort.

These windows are economical in comparison to teak and other good grade wood, and hence commercially viable as well. Other than this, these windows offer great comfort to the building community as they can be easily fixed at the final stage, and, therefore, construction time can be reduced. It also enhances the aesthetics of the buildings.

Today, there are windows which have inherent thermal insulation features, which can be enhanced with double glazing, thus reducing heat transfer through the windows. This leads to improved thermal performance, helping homeowners to immediately lower heating/cooling costs. With up to 40 per cent of a home's energy for cooling or heating being lost or gained through windows, improving their

thermal performance is necessary to reduce energy costs and India's GHG emissions. It is also imperative that government steps in to reduce or eliminate the use of wooden windows in large townships, commercial buildings, and institutions.

Zero-Energy Buildings: An Innovative Concept

A zero-energy building, also known as a zero net energy (ZNE) building, net-zero energy building (NZEB), or net zero building, is a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site. Researchers from the University of New South Wales in Australia have found a new thin-film technology known as CZTS to make a zero-energy building. These flexible solar cells have achieved highest efficiency. They are not just cheaper, but also non-toxic. The US National Renewable Energy Laboratory (NREL) confirmed its efficiency at 7.6 per cent in a one square centimetre area of the CZTS cell. At present, thin-film photovoltaic cells are used mainly in large solar power farms. However, they contain high cadmium, making it toxic and unsuitable for residential systems. Some thin solar cells, such as CIGS cells are commonly used on rooftops in countries like Japan. In most cases though, architects have used conventional solar panels made from crystalline silicon.

Till date, zero-energy buildings were stalled only due to the cost of the thin-film solar cells, which were used in facades, roofs, and windows. Also, these were made from scarce and highly toxic materials. Unlike other thin film cells, CZTS cells are made from abundant materials, including copper, zinc, tin and sulphur. Though conventional cells are cheaper than the newly innovated CZTS cells, they cannot be flexible, used for curved surfaces or can be easily integrated into building structures. These cells have an added advantage. They can be directly deposited on the material as thin layers since they are 50 times thinner than a human hair. This eliminates the need to manufacture silicon wafer cells and interconnect them separately. Researchers believe that this innovation can be integrated into buildings and electricity can be generated from sun through structures such as glazing, facades, roof tiles, and windows. This new cell is a new milestone and is posed to bring in energy efficiency to over 20 per cent.

Use of Architectural Glass

With the expansion of sustainable buildings, glass has become a subject of important research with two environmentally responsible feats—

transmitting light and blocking heat. Low emissivity (Low-E) is a kind of glass which is capable of radiating, or emitting, low levels of radiant thermal (heat) energy. This development led to greater efficiency in performance of glass through a measure called light-to-solar gain (LSG). This is a ratio which compares environmental attributes of various types of architectural glasses. In the US, the government is strongly encouraging architects and building owners to use energy-efficient glass. A study which compared performance of six types of glasses showed that low-e glass can be a solid long-term investment, for both financial and environmental reasons. In the study, the energy and equipment cost of window-walled, eight-storey building in six cities were looked at. For instance, there was a comparative analysis between glazed dual pane, tinted glass and a clear, double silver coated, solar controlled, low-e glass. The observations recorded an annual energy savings across all these cities. These savings ranged from $27,488 in Phoenix to more than $60,000 in Chicago. Saint-Gobain, one of the leading companies in glass manufacturing, came up with electrochromic glass and widen its appeal to the commercial building sector, where new regulations favour energy-efficient buildings. The Lawrence Berkeley National Laboratory, part of the US Department of Energy estimated that electrochromic technology can reduce a commercial building's peak energy demand by 20–30 per cent.

There are several factors that will contribute to the growth of the electrochromic glass market, but the most important will be the new regulation in Europe, where all new buildings will have to be net-zero in energy consumption by 2020, according to a sustainable building materials analyst from Lux Research. According to another study done by BCC Research, the wider 'active glass' market, including those glasses that become opaque or heat up by a switch, is expected to reach nearly $4.2 billion in 2016 from $1.6 billion in 2011. Since this technology can save energy using solar power, it holds promise for a much wider and profitable market like commercial buildings. Apart from low-e glass and elecrochromatic glass, thermal insulated glass is also used. This has a microscopically thin and transparent metallic coating, which helps in reflecting long-wave heat radiation. This helps in retaining heat within a building during winter, while optimizing light transmission.
It is believed that using thermal

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insulated glass in combination with solar control glass in a double-glazed unit is the best way to maximize the energy efficiency of windows and facades. Also, self-tinting glass can help cut down on air conditioning and heating bills. It also eliminates the need for extra elements, such as window shades or blinds. Choosing the right energy-efficient glass lets you control how much heat enters or escapes from a building.

Energy optimization designs according to climatic conditions of the place can be done using alternative energy techniques. Passive heating and cooling systems, for instance can maintain indoor temperature. Absorbing heat from the sun would depend on the thickness of the wall, roofing systems, and efficient glazing of the windows. For instance, in windows, double- and triple glazed are preferred to single glazed due to low thermal transmittance. These depend on window type and insulation material used in the building. In some buildings, heating water takes more energy than space heating. For such purposes, solar heating systems can be a good alternative. According to a study, solar water heating system with electrical backup reduced GHG emission by 74.2 per cent. To add, behavioural changes in people, such as taking shorter showers and lowering water heater temperature settings can impact energy use. Further, buildings can reduce their impact on environment through reuse and recycle. Construction waste can be reused effectively if appropriate systems are in place for collection and use.

Managing and Monitoring Energy Use

Schneider's EcoStructure™ is an award winning energy management architecture, which enables customers to analyse their energy and sustainability data at a local and global level. This energy architecture tool has been executed in projects across Telecom, IT/ITES, hospitality, and healthcare sectors across India. There is demand for Integrated Building Management System (IBMS) across India, and customers are looking for systems that provide common platform for energy management in their buildings. These systems give enterprise applications that not only integrate control and operate buildings on a single platform but also give information to improve operational efficiency through analytics. The IBMS technology is not just green due to energy savings, but also improves energy efficiency in the building. The green technologies, mainly for buildings, have become extremely relevant and critical to have due to fast increasing regulatory norms on sustainability and raising energy costs. In a non-industrial enterprise, buildings consume maximum energy and with this, they have the capability to prove the sustainability of enterprises.

The customers can review the performance of their buildings and services on a real time basis. This enables them to deploy targets and action plans to reduce energy consumption and improve productivity and reduce carbon footprint. There are many areas in a building where energy efficiency can be improved. Depending on the facility (office building, healthcare, data centre, and so on), areas for energy efficiency can be identified. Central Heating Ventilation and Air-Conditioning (HVAC) systems, Data Centre, IT systems, and lighting provide good scope for improving energy efficiency as these systems consume over 60 per cent of energy in buildings. Common platform based building systems provide scope for monitoring, analysing, and control parameters to enhance energy efficiency.

Voluntary green rating programmes for buildings have also started. But, the scale of its application is still very limited. There is a strong need for awareness campaigns to create demand for green buildings in India. The green building movement in India can be successful only if people understand the tangible benefits from resource savings that offset the costs of investment in resource efficient buildings. By enabling consumer movement through an information network built around the strategies for fuel savings, availability, costs, financial incentives, energy efficiency labelling of the products, water auditing, environment-friendly building designs, labelling of products based on efficiency, etc., awareness can be spread. Further, the report says that 66 per cent of the respondents considered reducing energy consumption as the top environmental priority for building green structures.

Table 1: Expected business benefits of green buildings in India

	New Green Building	Green Retrofit
Decreased operating costs over one year	10%	11%
Decreased operating costs over five years	15%	16%
Payback time for green investments (years)	4	5

Source: Dodge Data and Analysis Report

Table 1 gives information about the expected business benefits of green buildings in India.

The Future Rests with Energy-Efficient Buildings

In Jakarta, the Pertamina Energy Tower, a 523-metre tower, driven by energy efficiency, will be a landmark in Indonesia, and is expected to be completed in 2020. The building is designed with many overlapping energy strategies to keep it cool uninterruptedly. Through minimal insolation and maximized daylight, this project will meet its energy needs by geothermal energy to power the entire Pertamina campus. Additionally, the project will generate energy from the sun through shade canopies made of photovoltaics along campus paths. On the tip of the tower, wind energy will be used. By using a combination of renewable energy technologies, this campus is all set to be the largest net-zero energy projects in the world. The project is also water-efficient. The rainwater is recycled to cool the tower for irrigation and toilets or returned to the aquifer through a recharging well.

Another green building that will be known for its energy efficiency is the building campus in Doha, Qatar. This is a climate responsive building. According to the Qatar National Vision 2030, the country has a master plan to build Qatar Research and Development Complex over an area of 40.3 hectares. This campus is seeking Leadership in Energy and Environmental Design (LEED) certification. The plan is to implement shading and cooling strategies that will give a conducive environment and comfortable space for pedestrians all through the year using trees as key design elements. The cooling strategies included using recycled water from air-conditioning condensate to create cooling walls, benches, and shade structures with motion sensor-activated fans and cooling mists. Traditional water cooling techniques were used in this kind of desert architecture with motion sensors, just so that it is used only when people are around.

Biomimicry: The Future of Sustainable Habitat

Apart from constructing exclusive green buildings, another concept which has caught up with architects is biomimicry. One of the landmark projects inspired by nature is the Eastgate Centre in Harare, Zimbabwe. This building, which typifies the best form of green architecture, has taken its design form from a termite mound. The design mechanisms in the building were inspired by the self-cooling termite mounds in Africa. This building is a perfect example of how termite mounds have inspired clever ventilation systems in architecture. This not just reduces energy usage in the building, but reduces the cost as well. The building has no conventional air-conditioning or heating. Even then the temperature in the building stays in control throughout the year. Adding to this is the fact that there is significant energy savings to it. Termites in Zimbabwe build colossal mounds, within which they farm a fungus, because that is their primary food source. The fungus must be kept at exactly 87 °F.

The termites achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the entire day. Also, there are fantastic convection systems at place here. The air is sucked in at the lower part of the mound, down into enclosures with muddy walls. Then it goes up through a channel to the peak of the termite mound. The tireless termites then constantly dig new vents and plug up the old ones to keep the temperature perfect. The Eastgate Centre has a ventilation system which functions similarly. The outside air that is drawn in is either warmed or cooled by the building mass. This depends on which is hotter—the building concrete or the air. The air is then vented into the building's floors and offices before they exit through the chimneys at the top.

Another important feature here is the free movement of air between two buildings due to open space. This space is covered by glass and open to local breeze. The air is continuously drawn from this open space and this is done by the fans on the first floor. This air is then pushed up vertically through sections of ducts that are located in the central part of each of the two buildings. The fresh air replaces stale air that rises and leaves through exhaust ports in the ceilings of each floor. Finally, it enters the exhaust section of the vertical ducts before it is finally out through the chimneys. The Eastgate Centre uses less than 10 per cent of the energy of a conventional building of its size. As a result, the owners of this building have saved $3.5 million, just by not investing on an air-conditioning system. Further, due to its eco-efficient ways, the savings percolate to the people who have taken the building for rent. They save a good 20 per cent lesser than occupants in the surrounding buildings. This replication is not just a climate control solution but also extremely cost effective.

In India, 'Biomimicry India' was started by two architects—Seema Anand and Prashant Dhawan. In 2015, they set up a biomimicry lab with Srishti Institute of Art, Design and Technology, and are training many architects to promote this methodology. With smart cities and 'Make in India' initiative gaining momentum, there are immense opportunities for biomimicry architecture.

The Way Ahead

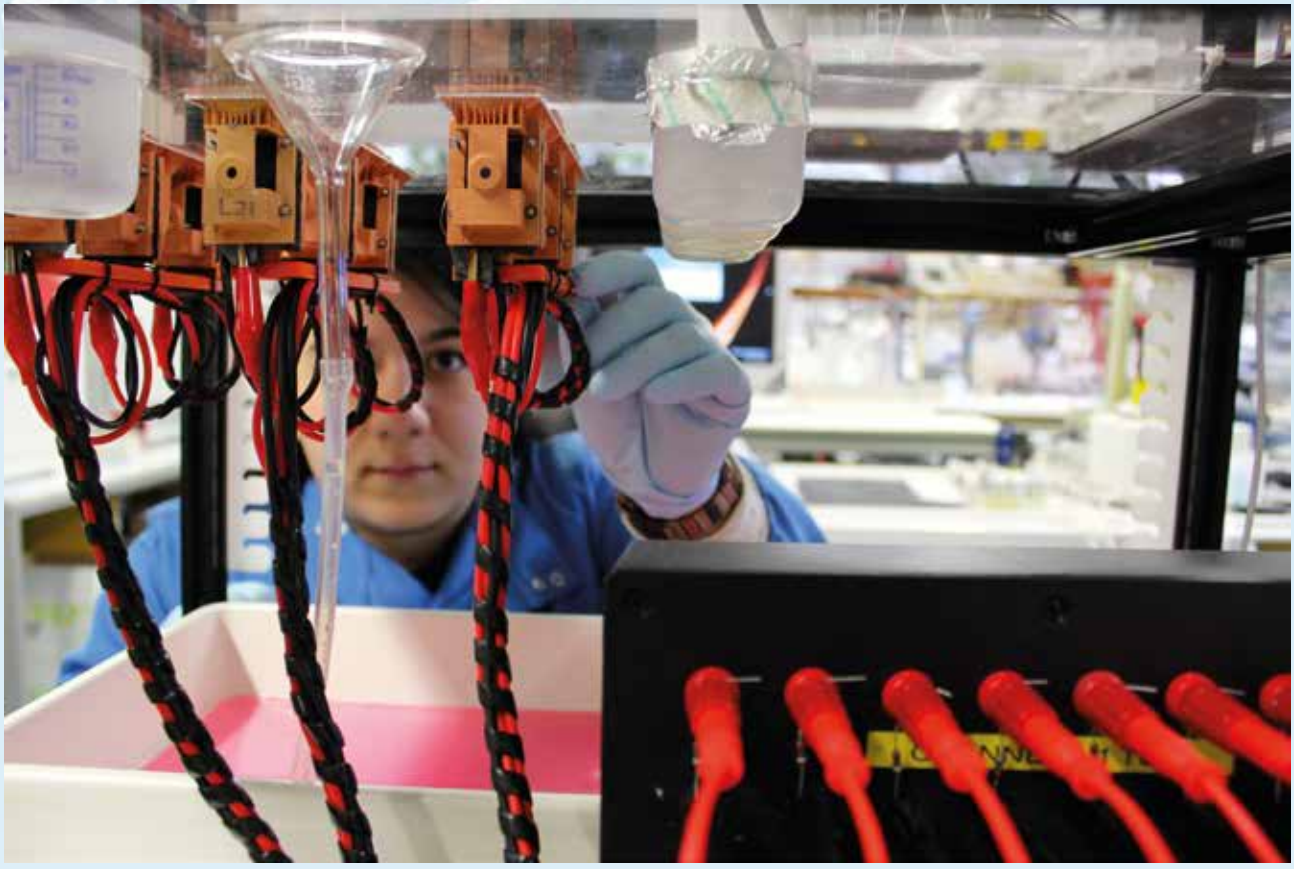
Experts strongly believe that it is crucial to have policies in place, at both national and global level. This can happen through appropriate technological interventions, such as efficient heating, cooling, improved lighting efficiency, wide deployment of carbon-free technologies, such as heat pump, solar thermal, etc. Further, experts say that building standards are effective when they are made mandatory and not voluntary. Developed countries like Germany have moved towards mandatory building energy standards, unlike India where there are voluntary standards in the form of GRIHA and LEED. Energy consumption in India is expected to increase as much as 131 per cent in 2050 due to increase in new construction (in comparison with 2005) and increasing standard of living. The carbon emissions could increase by 200 per cent, which indicates a need to have robust green building policies. For successful green building projects, there must be proper funding, political willingness, and long-term vision from the government. Only effective policies, as a package can work in promoting construction of green buildings in India. EF

Ms Sharada Balasubramanian is an environmental journalist who has been keenly writing on water, conservation, energy, and rural development for the last several years. Her stories and articles are linked to understanding the linkages of these issues to people, development, and economics. Email: sharadawrites@gmail.com. The author gratefully acknowledges the use of several sources from the internet in writing this article.

MICROBIAL FUEL CELLS

Opening Immense Energy Possibilities for the Future

In this article, **Dr Mamta Baunthiyal** and **Kavish Rajput** discuss that microbial fuel cells (MFCs) are one of green energy sources because MFCs use microorganisms as a substrate and possesses active electrodes while using the microorganism metabolism to produce electricity. MFCs have the potential for widespread application in locations lacking electrical infrastructures and also to expand the diversity of fuels we require—fulfilling our energy requirements in the coming years. Keep reading to know more…



Microbial Fuel Cell (MFC) technology represents a novel addition to the inventory of alternate energy sources having minimal or no net-CO_2 emission by generating electricity from what would be considered as waste. Microbial fuel cell or biological fuel cell is a bioelectrical system that drives a current by using bacteria and mimicking bacterial interactions found in nature. They have been described as "bioreactors that convert the energy in the chemical bonds of organic compounds into electrical energy through catalytic activity of microorganisms under anaerobic conditions". MFCs are not new, the concept of using microorganisms as

Gene Snider's two-chamber MFC with a salt bridge

Source: www.engr.psu.edu

catalysts in fuel cells was explored since the 1970s and microbial fuel cells that could treat domestic wastewater were presented in 1991.

MFCs have the following operational and functional advantages over the technologies currently used for generating energy from organic matter:

- MFCs have high conversion efficiency as there is direct conversion of substrate energy to electricity.
- In contrast to all current bio-energy processes, MFCs operate efficiently at ambient, and even at low temperatures.
- MFCs do not require gas treatment because the off-gases of MFCs are enriched in carbon dioxide and normally have no useful energy content.
- MFCs do not need extra energy input for aeration, provided the cathode is passively aerated.

In MFCs, organic matter works as substrate and microorganisms work as enzymes, which actively catabolize the substrate. During this process, electrons and different ions are produced and bioelectricity is generated.

Working of a Microbial Fuel Cell

The principle of working of MFCs is based on the tenets of microbial physiology coupled with electrochemistry. Structural design of MFCs brings the nuances of electrical and materials engineering to the fore. Approximately, all MFCs consist of anode and cathode chambers, physically separated by a proton exchange membrane (PEM). These chambers are also known as aerobic chamber and anaerobic chamber, respectively (Figure 1). The aerobic chamber consists of a positively charged electrode, which is bubbled with oxygen while the anaerobic chamber is devoid of oxygen that allows a negatively charged electrode to act as the electron receptor for the bacterial processes. Both chambers are separated by a semi-permeable, cation-specific membrane or a salt-bridge, to keep oxygen out of the anaerobic chamber while still allowing hydrogen ions (H^+) to pass through.

Please note the following processes in Figure 1:

1. The bacteria on the anode decompose organic matter and liberate H^+ ions and electrons.
2. Electron transfer from the bacteria to the anode can be accomplished by electron mediators or shuttling agents, directly by the cell or by means of 'nanowires'.
3. These electrons are directed to the cathode across an external circuit and for every electron conducted, a proton is transported across the membrane to the cathode for completing the reaction and sustaining the electric current.
4. The H^+ ions flow through the semi-permeable membrane to the

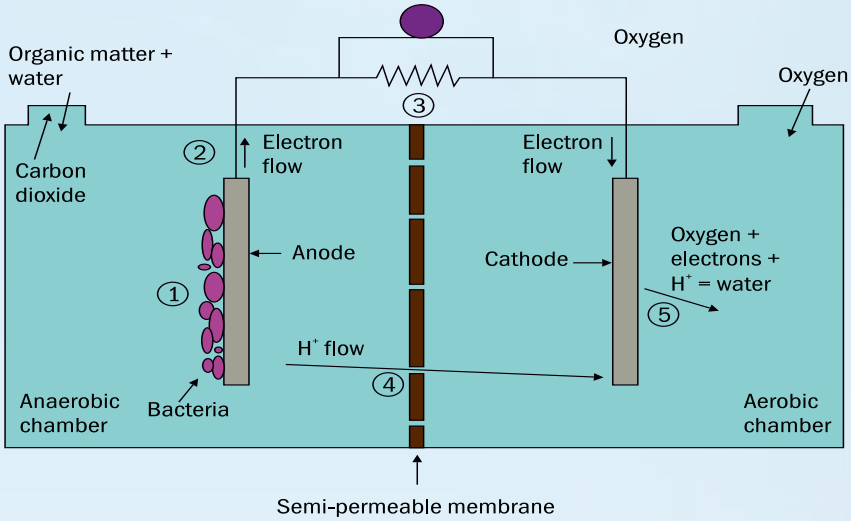


Figure 1: A schematic representation of a microbial fuel cell

Source: www.illumin.usc.edu

cathode. This complete process is driven by the electro-chemical gradient resulting from the high concentration of H^+ ions near the cathode.

5. The electrons from the cathode combine with dissolved oxygen and the H^+ ions to form H_2O.

In the anaerobic chamber, circulation of the solution containing substrate which is required for the bacteria is done. This substrate consists of glucose or acetate, compounds commonly found in food waste and sewage. The bacteria metabolize substrate by first breaking apart the substrate molecules into hydrogen ions, carbon dioxide, and electrons. The typical electrode reactions are shown below using acetate as an example substrate:

$CH_3COO^- + 2H_2O \rightarrow 2CO_2 + 8e^- + 7H^+$
(anodic reaction)

$4H^+ + O_2 + 4e^- \rightarrow 2H_2O$
(cathodic reaction)

As shown in Figure 2, bacteria use the electrons to produce energy by the process of the electron transport chain. Electron transport chain is disrupted by the MFCs by using a mediator molecule to shuttle electrons to the anode. An MFC is an extension of the electron transport chain where the last step of the process, i.e., the combination of oxygen, electrons and water formed from H^+ is transferred outside the bacterial cell from which the energy can be harvested.

Figure 2 illustrates the chemical compounds proposed to be involved in the electron transportation from electron carriers in the intracellular matrix to the solid-state final electron acceptor which is anode in metal reducing microorganisms, such as *Shewanella putrefaciens, Geobacter sulferreducens, Geobacter metallireducens, and Rhodoferax ferrireducens* which transfer electrons to the anode using this system. Mediators play an important role in electron transport for those microbes that are unable to transfer the electrons to the anode. Mediators shuttle between the anode and the bacteria transferring the electrons. They take up the electrons from microbes and discharge them at the surface of the anode. *Actinobacillus succinogenes, Desulfovibrio desulfuricans, Escherichia coli, Proteus mirabilis, Proteus vulgaris,* and *Pseudomonas fluorescens* need extraneous mediators while some microbes can provide their own. For example, *Pseudomonas aeruginosa* produces pyocyanin molecules as electron shuttles.

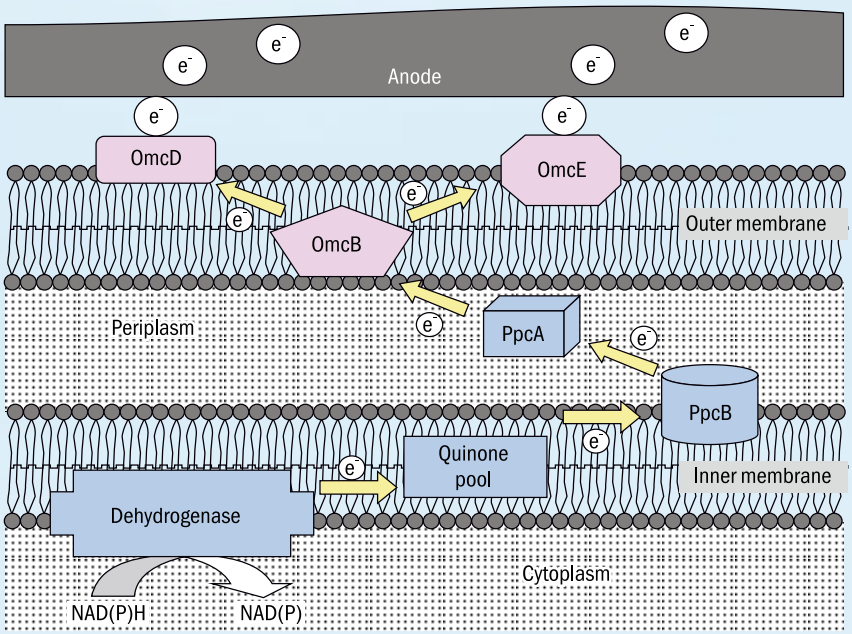


Figure 2: Components proposed to be involved in the electron transport from cells to the anode in MFCs using metal reducing microorganisms *(Geobacter* species). *Geobacter sulfurreducens* proteins (OmcB, OmcD, OmcE, PpcA, PpcB)

Source: Du Z, et al.2007. *Biotechnology Advances* 25: 464–482

To evaluate bacterial electricity generation, metabolic pathways which command microbial electron and proton flows must be determined. In addition to the impact of the substrate, the bacterial metabolism can be determined by the potential of the anode. Potential of the anode can be decreased by increasing the MFC current, forcing the bacteria to deliver the electron through more reduced complexes. Bacteria can use the respiratory chain in an oxidative metabolism at high anodic potentials. NADH dehydrogenase, ubiquinone, coenzyme Q or cytochrome was used for the transport of electrons and protons. High energy efficiencies of up to 65 per cent can be yielded by processes using oxidative phosphorylation observed in MFCs. Examples are the association containing *Pseudomonas aeruginosa, Enterococcus faecium, and Rhodoferax ferrireducens.* An overview of different bacterial species and their (putative) electron transport pathway is given in Table 1. If the anode potential decreases in the presence of alternative electron acceptors such as sulphate, the electrons are likely to be deposited onto these components. Methane production has repeatedly been observed when the inoculum was anaerobic sludge indicating that the bacteria do not use anode. If no sulphate, nitrate or other electron acceptors are present, fermentation will be the main process when the anode potential remains low. For example, during fermentation of glucose, possible reactions can be:

$C_6H_{12}O_6 + 2H_2O \rightarrow 4H_2 + 2CO_2 + 2C_2H_4O_2$

OR

$C_6H_{12}O_6 \rightarrow 2H_2 + 2CO_2 + C_4H_8O_2$

This shows that a maximum of one-third of hexose substrate electrons can theoretically be used to generate current, whereas two-thirds remain in the produced fermentation products, such as acetate and butyrate.

Microbes Used in Microbial Fuel Cells

Earlier, it was thought that only few microorganisms were used for the production of electricity. However, in recent years it is observed that most of the microorganisms can be utilized for use in MFCs. Microbial fuel cell concept was demonstrated as early as in 1910 where *Escherichia coli* and *Saccharomyces* sp. were used to generate electricity using platinum electrodes. This concept did not gain much attention till the early 1980s when it was boosted with the advent of the use of the electron mediators to enhance the generation of electricity many folds. Oxidized mediators are easily reduced by capturing electrons from within the membrane of microorganisms. The work of mediators can be described as they first transfer across the membrane and release the electrons to the electrode and then become oxidized again in the anodic chamber and, thus, mediators are

reutilized. Good mediators should have the following characteristics: (i) Should be cell membrane permeable; (ii) Should have electron affinity more than the electron carriers of the electron transport chain; (iii) Should possess a high electrode reaction rate; (iv) Should be well soluble; (v) Should be non-toxic to microbes and completely non-biodegradable; and (vi) Should be of low cost.

Table 1: Bacterial species identified in microbial fuel cells and their possible metabolism and pathway of electron transfer

Metabolic Type	Transfer Type	Example of Organisms	Terminal Bacterial Electron Shuttle	Added Redox Shuttle
Oxidative metabolism	Membrane driven	*Rhodoferax ferrieducens*	Unknown	–
		Geobacter sulfurreducens	89 kDa c-type cytochrome	–
		Aeromonas hydrophila	c-type cytochrome	–
	Mediator driven	*Escherichia coli*	Hydrogenase	Neutral red
		Shewanella putrefaciens	Quinones	–
		Pseudomonas aeruginosa	Pyocyanin, phenazinecar-boxamide	–
		Erwinia dissolvens	Unknown	Fe(III) CyDTA (an iron chelator)
		Desulfovibrio dessulfuricans	S^{2-}	–
Fermentative metabolism	Membrane driven	*Clostridium butyricum*	Cytochromes	–
	Mediator driven	*Enterococcus faecium*	Unknown	Pyocyanin

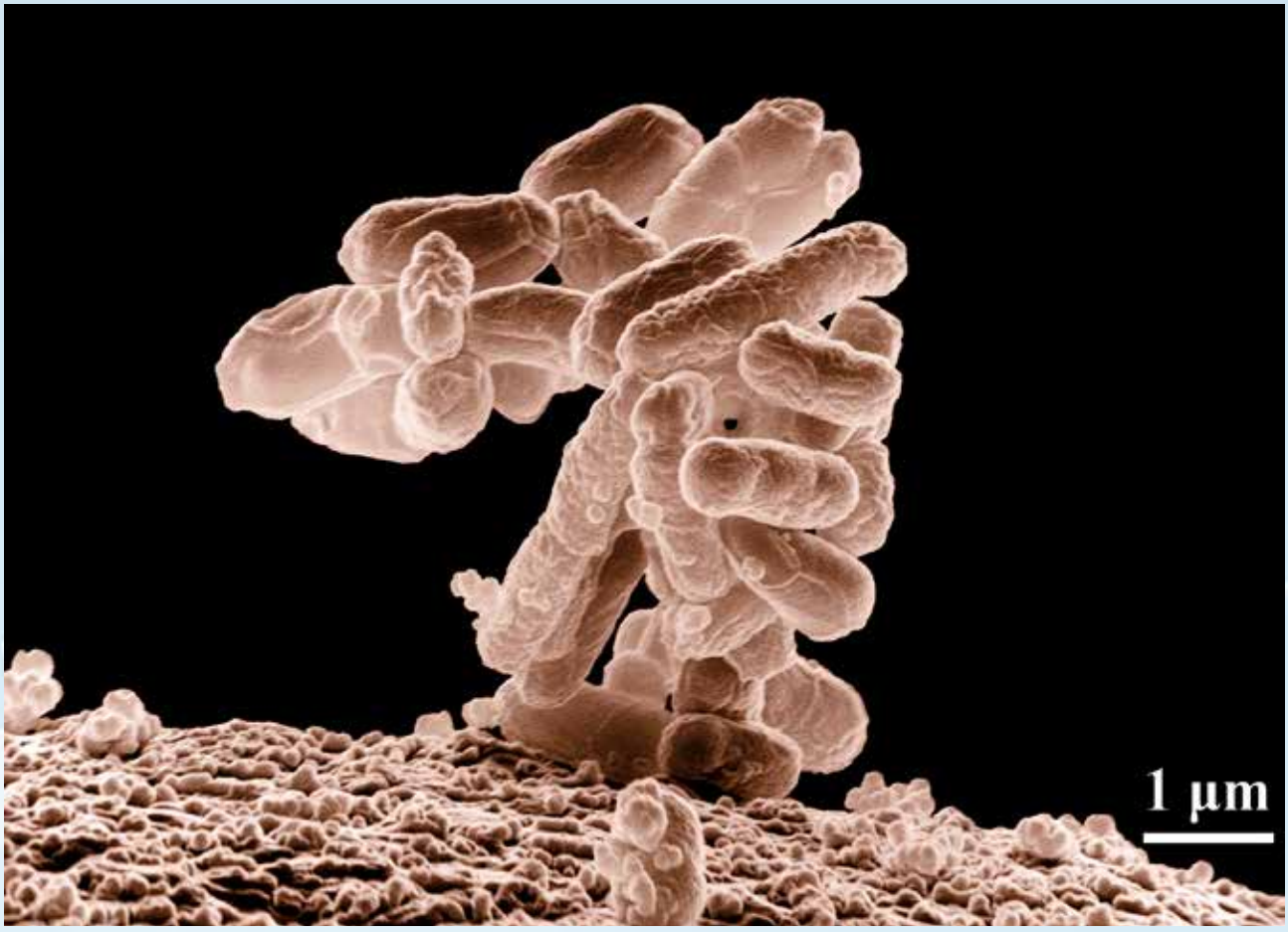
Source: Rabaey K and Verstraete W. 2005. *Trends in Biotechnology* 23(6)

Basic Components of Microbial Fuel Cells

MFCs basically consist of three materials for their construction, that is, anode, cathode, and membrane.

Anode

Materials used in anode must be conductive, biocompatible, and chemically stable in the reactor solution. Graphite, graphite felt, carbon paper, carbon-cloth, platinum (Pt), Pt black, reticulated vitreous carbon (RVC) are used. Metal anodes consisting of noncorrosive stainless steel mesh can be utilized, but copper is not useful due to the toxicity of even trace copper ions to bacteria. Carbon is the most versatile electrode material available as compact graphite plates, rods or granules used as fibrous material (felt, cloth, paper, fibres, foam), and as glassy carbon. To increase the anode performance different chemical and physical strategies have been followed. Scientists have incorporated Mn (IV) and Fe (III) and used covalently linked neutral red to mediate the electron transfer to the anode.



Cathode

Graphite, graphite felt, carbon paper, carbon-cloth, Pt, Pt black, and RVC are used. Ferricyanide is very popular as an experimental electron acceptor in MFCs because of its good performance. The advantage of ferricyanide is the low over potential using a plain carbon cathode, which results in a cathode working potential close to its open circuit potential. The greatest disadvantage, however, is the insufficient reoxidation by oxygen, which requires the catholyte to be regularly replaced. The most stable electron acceptor is oxygen for a MFC due to its high oxidation potential, availability, low cost, sustainability, and the lack of chemical waste product.

Membrane

For the separation of the anode and cathode compartments, Cation Exchange Membrane (CEM) is used in the MFCs. The most commonly used CEM is Nafion (Dupont Co., USA), which is available from numerous suppliers (e.g., Aldrich and Ion Power, Inc.). Alternatives to Nafion, Ultrex CMI-7000 (Membranes International Incorp., Glen Rock, NJ) are well suited for MFC applications and are considerably more cost-effective than Nafion. In an MFC, when a CEM is used it is important to recognize that it may be permeable to chemicals, such as oxygen, other ions, organic materials used as the substrate and ferricyanide. The use of ion exchange membranes is constantly growing and more systematic studies are necessary to evaluate the effect of the membrane on performance and long-term stability.

Anodic chamber: Glass, polycarbonate, and Plexiglas are used.

Cathodic chamber: Glass, polycarbonate, and Plexiglas are used.

Electrode catalyst: Pt, Pt black, MnO_2, Fe^{3+}, polyaniline, and electron mediator immobilized on anode are used.

Applications of Microbial Fuel Cells

The MFCs have current and potential uses in the generation of bioelectricity, brewery and domestic wastewater treatment, desalination, hydrogen production, remote sensing, pollution remediation, and also as a remote power source.

Generation of bioelectricity

MFC is a fantastic technology, capable of converting the chemical energy stored in the chemical compounds in a biomass to electrical energy with the aid of microorganisms, that can use a wide variety of substrates, materials, and system architectures. Because chemical energy from the oxidization of fuel

molecules is converted directly into electricity instead of heat, the Carnot cycle with a limited thermal efficiency is avoided and theoretically a much higher conversion efficiency can be achieved (N70%) just like conventional chemical fuel cells. However, MFC power generation is still very low, that is because the rate of electron abstraction is very low. One feasible way to solve this problem is to store the electricity in rechargeable devices and then distribute the electricity to end-users. Capacitors were used in their biologically inspired robots named EcoBot I to accumulate the energy generated by the MFCs and worked in a pulsed manner. MFCs are especially suitable for powering small telemetry systems and wireless sensors that have only low power requirements to transmit signals such as temperature to receivers in remote locations. MFCs themselves can serve as distributed power systems for local uses, especially in underdeveloped regions of the world. Applications of MFCs in a spaceship are also possible since they can supply electricity while degrading wastes generated on board. It is particularly preferred for sustainable long-term power applications, with potential health and safety issues. The main objective of MFCs is to achieve a suitable current and power for the application in small electrical devices.

Brewery wastewater treatment

Wastewater of brewery and food manufacturing can be treated by MFCs. Wastewater is rich in compounds that can serve as substrate or food for the microorganisms. For the implementation of MFCs, breweries are ideal as their wastewater composition is always the same. These constant conditions allow bacteria to adapt and become more efficient. Currently, Fosters, an Australian beer company, has begun testing out an MFC to clean its wastewater while generating electricity and clean water.

Sewage treatment

MFCs are used in sewage treatment to decompose the waste organic material present within it. MFCs can enhance the growth of bio-electrochemically active microbes during wastewater treatment, thus, they have good operational stabilities. Research has shown that MFCs can reduce the amount of organic material present in sewage wastewater up to 80 per cent. The process is very similar to brewery wastewater treatment, with the difference being that the water must first be pre-treated to remove toxins and other non-biodegradable materials. This is a challenging step because sewage wastewater often varies in composition and may require extensive treatment before it can be cleaned by the MFC. However, this extensive treatment is justified by the electricity produced while cleaning the wastewater. The electricity production from MFCs will help to offset the high costs of processing wastewater. A novel MFC-membrane bioreactor (MBR) for the treatment of wastewater has recently been reported to achieve a maximum power density of 6.0 W/m^3 with the average current of 1.9 ± 0.4 mA and good pollutant removal performance attributed to the high biomass retention and solid rejection.

Desalination

The amount of energy required for the removal of the dissolved salts from the water shows significant problems in desalination of sea water and brackish water for use as drinking water. This process could proceed with no external electrical energy input by using an adapted MFC. Salt removal efficiencies of up to 90 per cent have been recorded in laboratory studies, but much higher removal efficiencies are required to produce drinking-quality water. Figure 3 shows the desalination by an MFC.

Hydrogen production

Hydrogen can be used as an alternative fuel, which can be generated by the use of MFCs. Hydrogen production by modified MFCs operating on organic waste may be an interesting alternative. For the production of hydrogen, the MFC is supplemented by an external power source to get over the barrier of turning all the organic material into hydrogen gas and carbon dioxide. In such devices, anaerobic conditions are maintained in the cathode chamber and additional voltage of around 0.25 V is applied to the cathode. Under such conditions, protons are reduced to hydrogen on the cathode. Such modified MFCs are termed bio-electrochemically assisted microbial

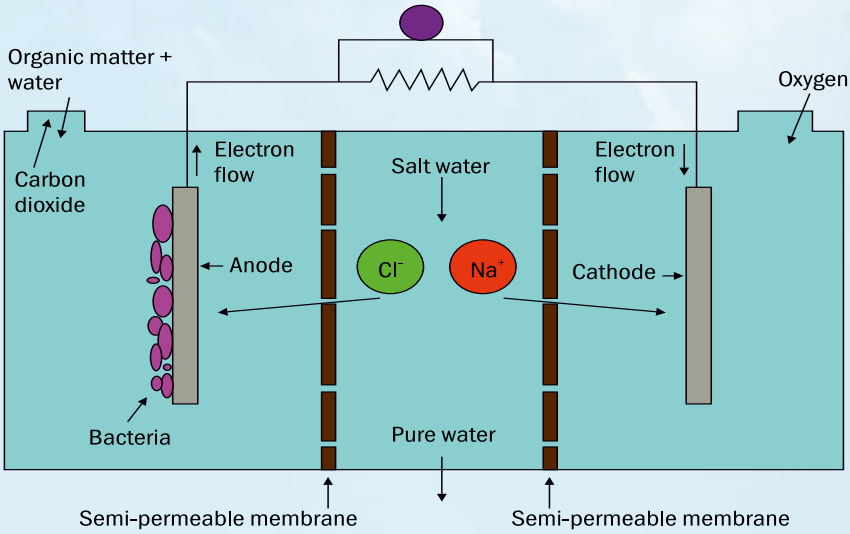


Figure 3: A desalination microbial fuel cell

Source: www.illumin.usc.edu

reactors (BEAMR). Although electricity is used instead of generated as in normal MFCs, this method of producing hydrogen is very efficient because more than 90 per cent of the protons and electrons generated by the bacteria at the anode are turned into hydrogen gas. Conventional production of hydrogen requires 10 times the amount of energy as an adapted MFC, making the MFC the most efficient and environment-friendly way to generate hydrogen for use as a fuel.

Bioremediation of water

One novel application of the MFC is as a method of bioremediation. Bioremediation of water containing organic pollutants, such as benzene, toluene, and compounds found in gasoline can be carried out using MFCs. Microbial fuel cell is designed in such a way that the fuel cell floats over the top of the polluted water. Remediation can include degradation of organic pollutants at the anode as well as reduction of inorganic chemicals. The sediment MFC consists of anode in the anaerobic sediment and cathode in overlying water containing dissolved oxygen. It suits river, lake, and coastline where sediments are full of organic carbon and exoelectrogenic bacteria already present in them. Also, it has been shown that MFC-based technologies could be used to remove nitrate, conversion to nitrite, and even N_2 gas from water, reduced by receiving electrons from the cathode.

Biosensors

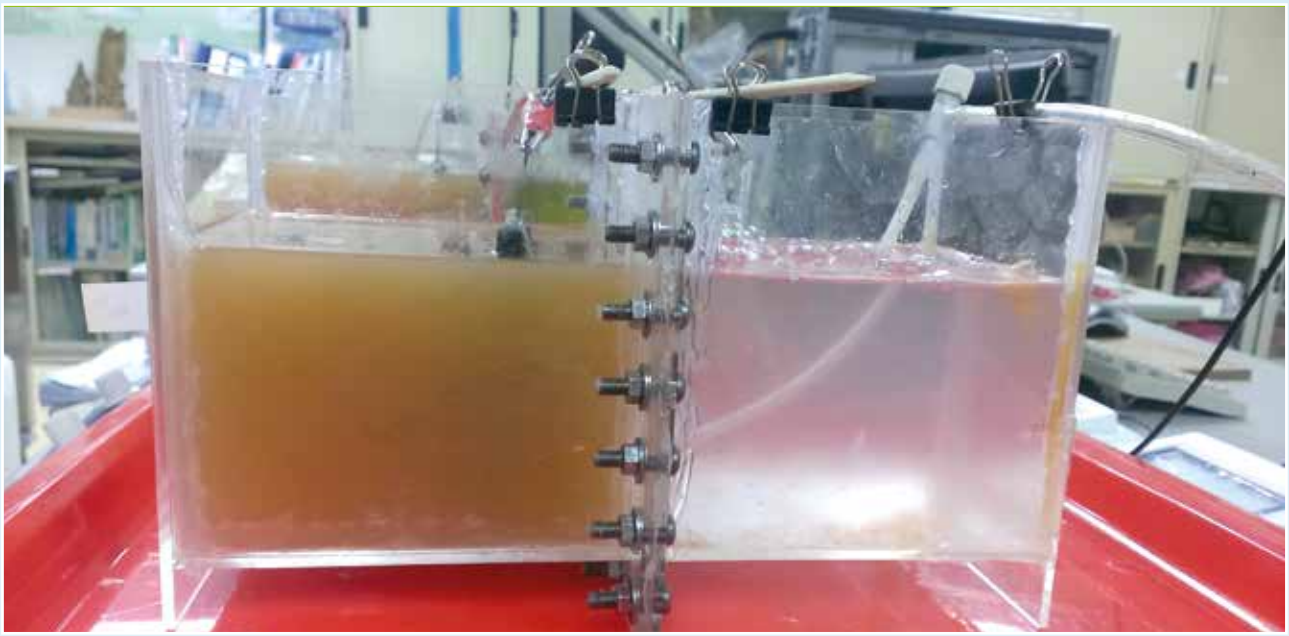
Apart from these applications, another potential application of the MFC technology is to use it as a biosensor. Sensor is used for pollutant analysis and in situ process monitoring control. Batteries have limited lifetime and must be changed or recharged; thus, MFCs are suitable for powering electrochemical sensors and are small telemetry systems to transmit obtained signals to remote receivers. To design this type of system, the first step is to have appropriate cathodic and anodic reactions. It is possible to use MFCs as biological oxygen demand (BOD) sensor, and it is exhibited that this type of BOD sensor has excellent operational sustainability and reproducibility and could be kept operating for five years. The proportional correlation between the Coulombic yield of MFCs and the strength of the wastewater makes MFCs possible BOD sensors.

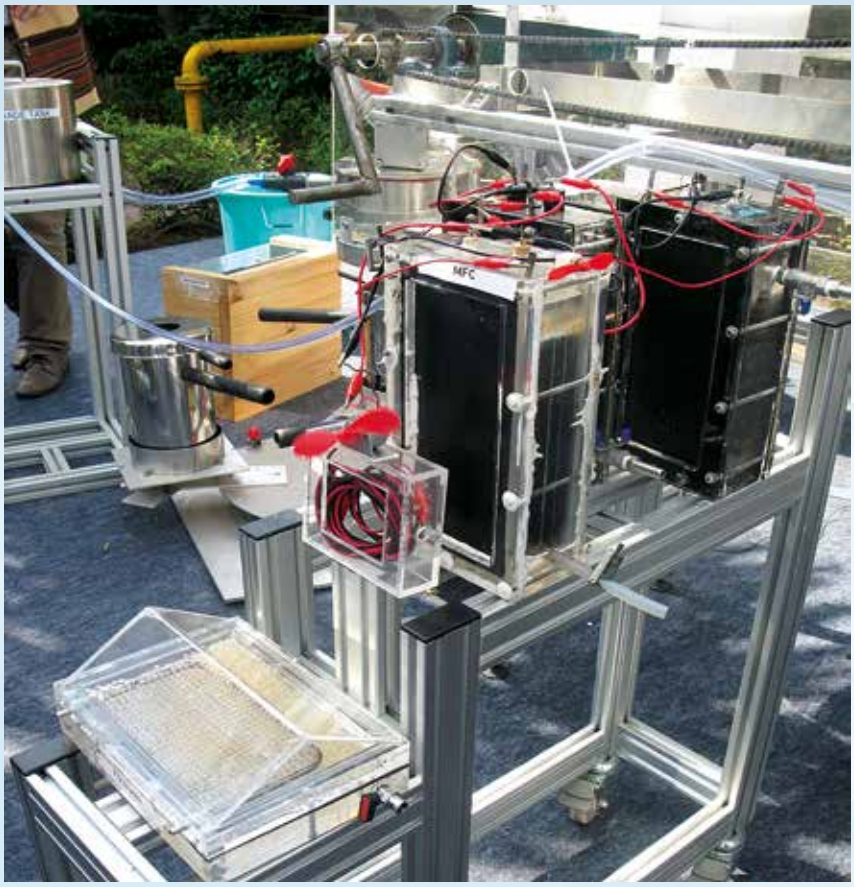
Limitations of Microbial Fuel Cells

The power generated by the MFC may not be enough to run a sensor or a transmitter continuously. This is the principal problem with using microbial cells. It can be solved by increasing the surface area of the electrodes. It is unrealistic to expect the power density output from an MFC to match with that of a conventional chemical fuel cell such as a hydrogen-powered fuel cell. The fuel in an MFC is often a rather dilute biomass (as in wastewater treatment) in the anodic chamber that has a limited energy (reflected by its BOD).

MFCs are in general slightly bigger than comparable batteries or engines. However, the size of the units is decreasing. Fuel cells are currently very expensive to produce, since most units are handmade. Some fuel cells use expensive materials. The technology is not yet fully developed and few products are available. Moreover, MFCs cannot operate at extremely low temperatures due to the fact that microbial reactions are slow at such temperatures.

When used in wastewater treatment, a large surface area is needed for





MFCs MAY HAVE OTHER APPLICATIONS IN FUTURE BESIDES WASTEWATER TREATMENT AND RENEWABLE ENERGY. BY EMPLACING THE ANODE ELECTRODE IN MARINE SEDIMENTS AND EMPLACING THE CATHODE IN THE OVERLYING WATER, IT IS POSSIBLE TO GENERATE ELECTRICITY FROM THE BACTERIAL DECOMPOSITION OF THE ORGANIC MATTER IN THE SEDIMENT. RESEARCH INTO ADVANCED MICROFLUIDICS, BACTERIAL STRAINS, MORE ROBUST SEPARATOR MEMBRANES, AND EFFICIENT ELECTRODES ARE THE KEY TO UNLOCKING THE POTENTIAL OF MFCs.

biofilm to build up on the anode. A breakthrough is needed in creating inexpensive electrodes that resist fouling.

Another limitation is the inherent naturally low catalytic rate of the microbes. Even at their fastest growth rate microbes are relatively slow transformers. Although Coulombic efficiency over 90 per cent has been achieved in some cases, it has little effect on the crucial problem of low reaction rate. Although some basic knowledge has been gained in MFC research, there is still a lot to be learned in the scale-up of MFC for large-scale applications.

Current Research

In order for MFCs to reach the point where they can produce electricity at a price competitive with other sources of energy, requires a greater understanding of MFC design and the interactions between the fuel cell anode and the electrigens need to be calculated. One key area of research is anode engineering and design. To overcome the impact of the power output, advanced materials, such as intertwined carbon nanotube textile fibres, have been developed. These carbon nanotube textile anodes not only provide a dramatic increase in the area available to receive electrons, but also greatly increase the area available to receive electrons and increase the efficiency of the system due to the decrease in the resistance resulting from the increased surface area.

Microbial Fuel Cells in the Future

MFCs may have other applications in future besides wastewater treatment and renewable energy. By emplacing the anode electrode in marine sediments and emplacing the cathode in the overlying water, it is possible to generate electricity from the bacterial decomposition of the organic matter in the sediment. Research into advanced microfluidics, bacterial strains, more robust separator membranes, and efficient electrodes are the key to unlocking the potential of MFCs. To improve the power density output, new anodophilic microbes that vastly improve the electron transport rate from the biofilm covering an anode to the anode are much needed. Mutagenesis and even recombinant DNA technology can conceivably be used in the future to obtain some 'super bugs' for MFCs. There is immense possibility that there are many microorganisms yet to be discovered that might be beneficial for electricity production. EF

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ENHANCING THE MARKET DEMAND FOR ENERGY-EFFICIENT MATERIALS AND TECHNOLOGIES

through National Green Building Rating System

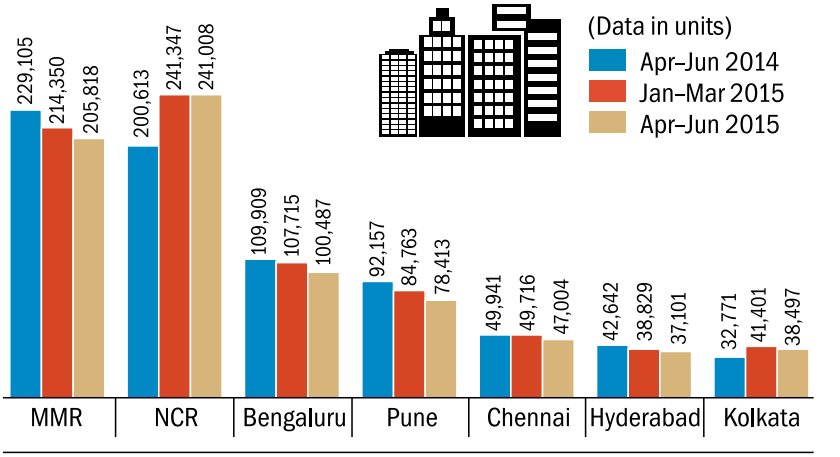
In this article, **Ar. Namrata Kaur Mahal** and **Ar. Aditi Phansalkar** emphasize the need of having context-specific architecture solutions instead of current contemporary design solutions which give less or no attention to the carrying capacity of the land, availability of basic resources, such as water and energy, embodied energy of the materials selected for construction, and so on. These modern designs are highly energy and resource intensive. However, since issues related to water, energy, and environment have taken precedence, it comes as a relief that the green building concepts and principles have been rediscovered in the form of a rating system. Keep reading to know more…

Housing in India is on the priority agenda of the new government, given that it reflects the socio-economic mix of its vast population on the global chart. In the year 2015, the Hon'ble Prime Minister of India, Shri Narendra Modi, had crafted the vision of 'Housing for All' by 2022. It is envisioned that by the time the nation completes 75 years of its independence, every family will have a *pucca* house with water connection, toilet facilities, 24x7 electricity supply and access.

Gap Between Infrastructure and Corresponding Market Development

While decoding the housing requirement for India, it was estimated that about 11 crore housing units would be required for the urban reform.

In pursuance of this commitment, the 2016 budget announces exemption from service tax on construction of affordable houses up to 60 square metres under any prevailing scheme of Central and State government, including the Public Private Partnership (PPP) schemes. While the milieu is being made conducive for achieving the objectives of the vision, on the other hand we have approximately 750,000 unsold flats in the top seven cities of the country which includes Mumbai Metropolitan Region (MMR), National Capital Region (NCR), Bengaluru, Pune, Chennai, Hyderabad, and Kolkata as seen in Figure 1. Approximately, there are 50,000 luxury apartments, priced at an estimated ₹one lakh crore, lying unsold in Mumbai alone. The number of vacant flats would definitely be more if taken altogether at the national level. Few developers are now reducing the sizes of the apartments to make them more affordable. The point here is that, there is a substantial gap between the



Residential includes apartments, villas, and independent floors
MMR includes Mumbai, Navi Mumbai, and Thane
NCR includes Gurgaon, New Delhi, Noida, Faridabad, Ghaziabad, and Greater Noida

Figure 1: Inventory of unsold housing units in the top seven cities of the country

Source: http://www.financialexpress.com

prerequisites of the country and the way the market is developing.

A similar gap exists when it comes to the need for offering context-specific architecture solutions versus the current contemporary design solutions. Apparently, to cater to the growing demand of housing, today buildings are constructed at a faster pace, in a modern way, where less or no attention is given to the carrying capacity of the land, availability of basic resources, such as water and energy, embodied energy of the materials selected for construction, and so on. It may also be noted that modern architecture is perceived or rather is identified by some very obvious and non-indigenous facets, such as glass facades and compact matchbox style designs and to our surprise they also call themselves 'green'. In reality, these designs are highly energy and resource intensive. These trends suggest significant and growing market opportunities for green buildings in India.

In spite of witnessing numerous benefits (environmental and monetary) of green buildings for decades together, the uptake for green buildings by government as well as private sector has been on a lower side. One of the reasons for the aforementioned could be attributed to lack of accessibility as well as availability of green building materials, products and technologies in the vicinity. However, given that the issues related to energy, water, and environment have taken precedence, the green building concepts and principles have been rediscovered in the form of a rating system. Today one of the most effective legislative instruments for promoting sustainable development is 'Rating System', where the performance of the built environment is measured under certain nationally accepted benchmarks.

GRIHA—A Common Connector

Green Rating for Integrated Habitat Assessment (GRIHA) is a national rating system for green buildings in India which was conceptualized by The Energy and Resources Institute (TERI) in the year 2005. It consists of 34 criteria categorized under various sections, such as sustainable site planning, water and energy optimization, sustainable building material, waste management, health and well-being, and building operation and maintenance. It is a point based rating system, where the project is evaluated out of 100 points (+4 points for innovation).

As the growing disconnect between the market and the practices is now well established, TERI's intervention in the form of GRIHA emerges out to be a strong instrument in India to establish the necessary connections. Having been adopted by the Ministry of New and Renewable Energy, Government of India (MNRE, GoI) and being highlighted in the Intended Nationally Determined Contributions (INDCs) document submitted to the United Nations Framework Convention on Climate Change (UNFCCC), GRIHA serves as an important platform to bring together diverse sectors by creating appropriate channels, which can again cater to the market demand and also achieve the objectives underlined in various policies and mission statements of the nation. Till date, 30 GRIHA rated projects have encouraged installation of 14.5 MWp of renewable energy system and have also led to a cumulative annual energy consumption reduction of 74,000 MWh. Furthermore, the anticipated impact of the 650 GRIHA registered projects would be installation of 315 MWp of renewable energy system and cumulative annual energy consumption reduction of 1,600,000 MWh. Thus, GRIHA directly or indirectly, through its mandatory and optional criteria, imbue usage of energy and resource efficient materials and technologies having minimal impact on the environment.

Figure 2 explains the possible channels that are desirous to create and drive the market for green materials and technologies. The mandatory Criterion 18 in GRIHA, which focusses on renewable energy utilization, states that minimum one per cent of the total connected load of the artificial lighting (internal and external) and space conditioning is to be met by renewable energy systems. This requires the need for the existence of dealers of renewable energy products. However, more obviously, the locational advantages of

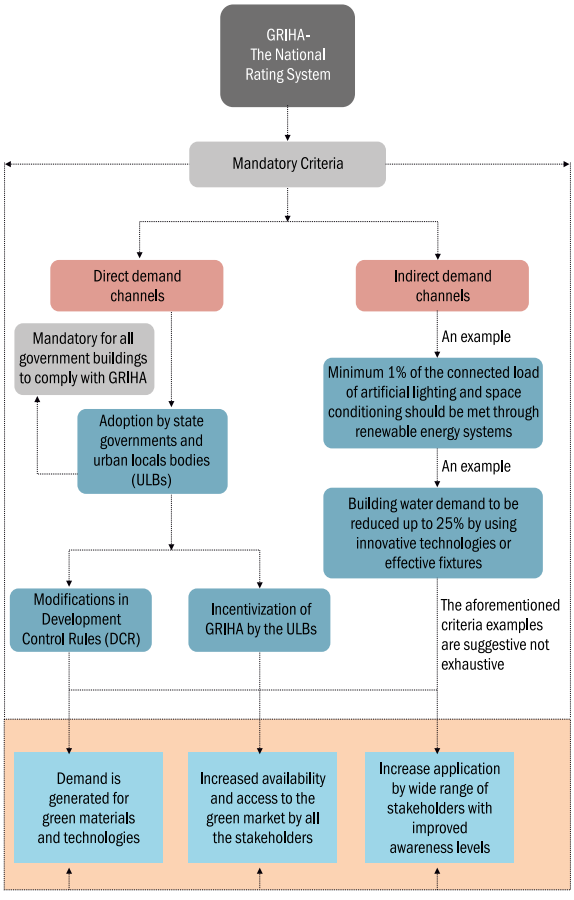


Figure 2: GRIHA as a medium to enhance market opportunities

being within the city premises, rather than being on the outskirts, falls on the benefit of both, the dealers as well as the buyer. This can facilitate the overall process of penetration of new and existing technologies, by generating demand and thereby developing suitable market.

In addition to mandatory criteria, which ensures the use of energy-efficient materials /technologies, the non-mandatory/optional criteria in GRIHA too, in certain ways, emphasizes innovative design solutions while also serving as a directive for suggesting appropriate materials. For instance, in GRIHA Criterion 5; reduce hard paving on site, more than 50 per cent of the total paved area is required to have pervious paving or open grid pavements or grass pavers or shading through the use of vegetated pergolas. The intent of this being, to increase the permeability of the surfaces, which may otherwise be vulnerable to become non-permeable, which can further restrict the percolation of rainwater in the ground and also add to the urban heat island (UHI) effect. This indirectly suggests open grid designs, thus directly generating demand for paver blocks with grass joints as a suitable material. This in turn creates, as well as justifies, the requirement for the existence of subsequent dealers around. Now, in the absence of such dealers in the vicinity or in the city or in the neighbourhood, the client chooses to either look for another option, compromising on the intent (of permeability and reducing UHI) or chooses to procure the same from a distant dealer, adding to the overall cost and carbon footprint as well. Such attributes eventually contribute to the popular myths that green buildings are expensive.

While we discussed the direct benefits to the users, developers and the market owners/dealers along with their subsequent roles, the urban local bodies (ULBs) too have a giant share to take away. If the ULBs adopt the rating systems, in addition to the resources conservation and associated reduction in the cost to treat it, they also become eligible for other monetary benefits from the central government. This monetary award can in turn enable the ULBs to undertake promotional activities for various aspects including significance of selecting local materials and technologies available within the city limits. Given that, lack of awareness and availability of authentic information are the most frequently cited barriers for green building growth across the globe, it is of paramount importance to raise the awareness level of the users and the relevant stakeholders by creating various platforms for information exchange and promotion of low embodied energy material and resource efficient technologies.

In the absence of such arrangements, green building or resource efficient buildings continue to remain an option for few. More than option, given its long lasting benefits to the users as well as other relevant stakeholders, the same is required to be a statutory action in cities. While, there still remains a lack of documentation of available materials and its access, there is a fervent need to work at both the ends, viz., demand generation as well as innovation and availability of cost-effective green materials. A detailed documentation of the same, in the form of a directory where, locally available green materials are listed would serve as a breather to the whirlwind of confusion persistent in the market.

Conclusion

Thus, GRIHA can be utilized as a potential tool as well as a medium to mobilize the necessary demand in the market for green materials and technologies. Adoption of GRIHA by the corporations shall definitely have far reaching benefits. The same also has immense potential to generate demand and give rise to subsequent market transformation. Research and development in this dynamic and versatile subject can also get the necessary boost while contributing significantly to the green building movement in India. EF

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GRIHA FOR GREEN BUILDINGS IN INDIA

Moving Ahead with the Nation

Since the year 2008, when the national green building rating system 'GRIHA' was officially launched, continuous changes and improvements have been taking place in the system. In this article, **D E V S Kiran Kumar** provides an overview of the advancements of the system towards enabling a stronger and wider implication of green building design, construction, and operation practices in the country.

Green Rating for Integrated Habitat Assessment (GRIHA) is India's national green building rating system for green buildings, which has been developed by The Energy and Resources Institute (TERI) and endorsed by the Ministry of New and Renewable Energy (MNRE). In the recent submission of India to the United Nations Framework Convention on Climate Change (UNFCCC), GRIHA was recognized as a tool to recognize and promote energy-efficient and green buildings in India.

The GRIHA was developed as an indigenous building rating system particularly designed to address climate specific requirements in the country. It encourages the use of traditional architectural techniques and is synchronized with government

policies and programmes. It provides an evaluation method to design, build, operate, and maintain a resource-efficient built environment. It can be applied to commercial, institutional, and residential buildings. It attempts to minimize a building's resource consumption, waste generation, and overall ecological/environmental impact by comparing them to certain nationally acceptable limits and benchmarks. The unique characteristic of this rating system is that it aligns with the requirements of various energy and environmental codes of India.

The rating system has been able to penetrate well in the market, since an independent body ADaRSH (Now GRIHA Council) was formed, with support from the MNRE. The council has been able to conduct awareness programmes for more than 20,000 professionals and there are more than 1,000 subject experts and professionals who have been qualified as GRIHA Evaluators and Trainers. The council has been working strategically with the patrons and industry associations located across the country. As per the latest data from the GRIHA Council, 725 projects are registered and about 120 (including 65 precertified) projects are certified under three variants of the rating system. These buildings fall under various building categories—most of them are office buildings, followed by institutional and residential building types (Figure 1). Figure 2 shows the statistics of increase in total built up area every year with respect to the total number of projects registered under GRIHA, since the beginning. It was estimated that the projects registered by mid-2015 have a potential of offsetting about 13 lakh tonnes/carbon emissions per annum by reducing operational energy consumption.

A working paper published by R Debjyoti *et al.* projects green premium cost for 5-star rating level as 5–10 per cent over the basic cost of the building (Figure 3). In another recent study carried out by TERI, it was estimated that the green features implemented under various categories of GRIHA rating namely, sustainable site planning, passive building design, building materials, energy-efficient lighting and comfort systems, renewable energy, and water efficient systems have payback of 1–3 years. It is, however, important to mention that the stringency of the rating system, as some of the buildings certified under both IGBC and GRIHA, could achieve only 4 stars as against IGBC platinum rated building. The Ministry of Urban Development (MoUD) and the MNRE and various urban local bodies (ULBs) across the country offer various incentives for wider implementation of GRIHA projects.

GRIHA system encourages green interventions from the concept stage itself in order to achieve holistic and well-integrated design. GRIHA team ensures this by organizing workshops for the design and construction team at the starting of the project and conducting due diligence visits during the construction process. The impact of GRIHA certified buildings is credible in the current smart city context. It gets reflected not only in energy and water consumption reduction, but also in terms of building material resource efficiency. Looking at the statistics of certified buildings till now, aspiration of GRIHA clients getting 5-star rating is much higher compared to other star levels. In total, about 20 MWp rooftop solar PV has been installed in these projects (Figure 3). This is an encouraging figure and shows

implementation potential of renewable energy in GRIHA projects aligning with energy policies of local bodies. On the supply side, some of the GRIHA rated projects are equipped with on-site/ off-site renewable energy with more than 100 kWp solar PV and to meet 100 per cent of building energy demand. Renewable energy technologies implemented in these include not only solar PV but also wind and biomass energy. GRIHA's requirement of renewable energy usage for hot water generation is based on total energy consumption. Thus, in hot and humid climates, where a full size solar thermal hot water system is not feasible, hybrid technologies including heat pump, solar PV, and solar thermal could be executed. On the demand side, the average energy performance index (EPI) of GRIHA rated projects is 82 kWh/sq. m/year. Cement used in these projects, on an average, have 30 per cent flyash content, showing resource efficiency potential of GRIHA system in using recycled building materials. Average reduction in terms of water consumption in these projects is 60 per cent from the base case, of having conventional water fixtures. It is estimated that a million sq. m GRIHA 5-star rated built up space could save electricity and water, equivalent to the energy consumed by 10,000 urban homes and water consumed by 3,000 urban homes, respectively.

Having significant experience of conducting more than 100 building energy audits and facilitating several major green projects in the country since the early 2000, TERI team has been contributing towards technical updates of the system to meet increasing demands of the industry. The rating system is known for its technical competency with respect to issues concerning India. Last year, there was an Analytical Hierarchy Process (AHP) survey conducted to revisit the priority areas of green building design and construction in the current context. The 34 criteria and the scoring for star rating have been completely revised as

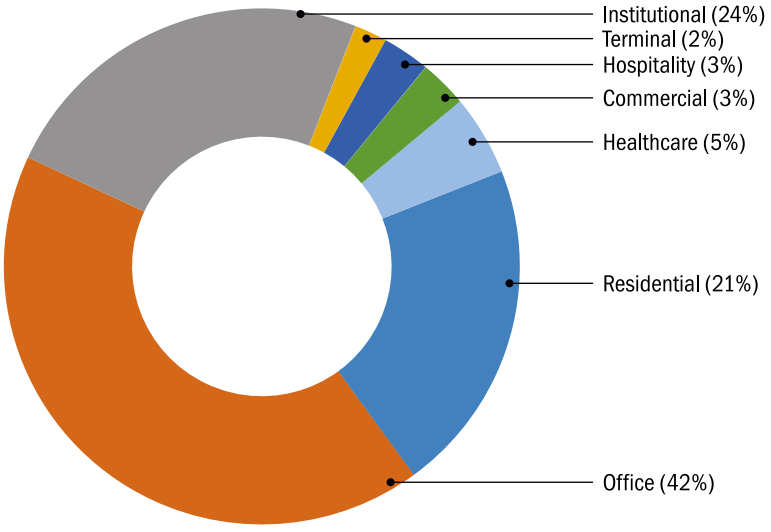

Figure 1: Distribution of building types rated under GRIHA

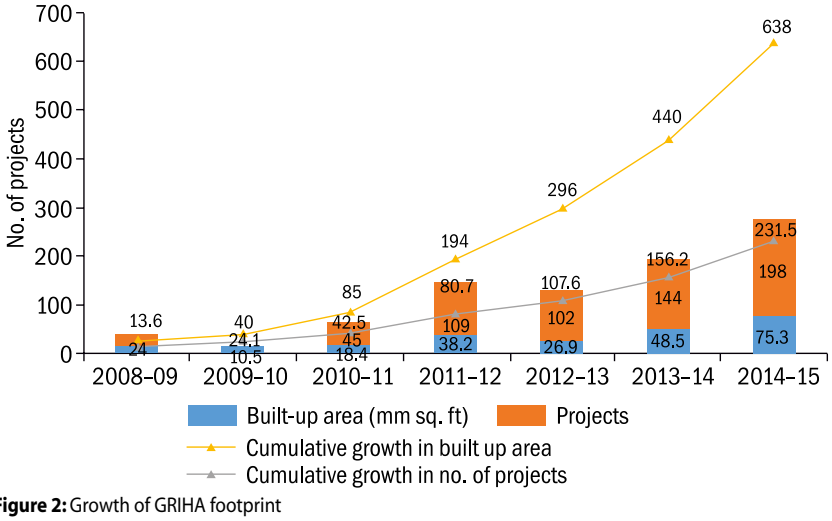

Figure 2: Growth of GRIHA footprint

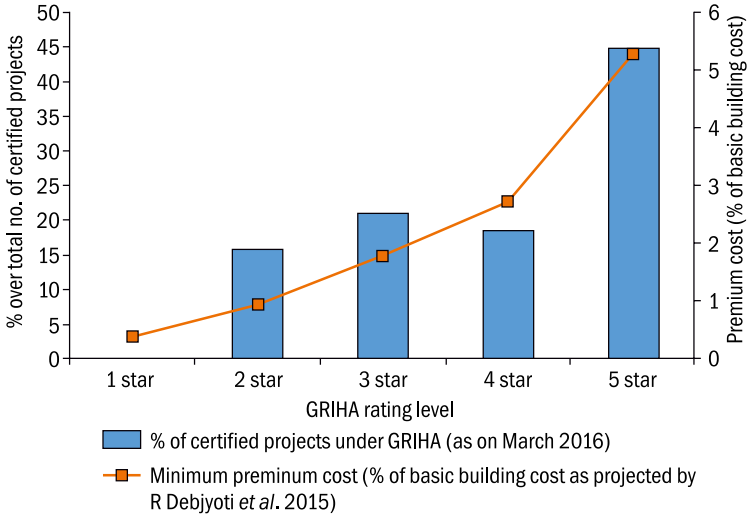

Figure 3: Green rating and the cost impact

given in the latest version of GRIHA 2015.

The SVAGRIHA system has been developed as an extension of GRIHA focussing on smaller building projects (≤ 2,500 sq. m built up area), which helps environmental building footprint at independent building owner level, but can also result into larger benefits upon wider implementation at the city level. The role of ULBs is essential in this development. For instance, the Pimpri Chinchwad municipality, where more than 100 projects are registered with GRIHA Council, is taking the lead and encouraging their citizens in this respect. SVAGRIHA is an affordable rating system where no green building consultant is needed to carry out the building energy modelling and facilitate the green building documentation. Buildings are evaluated based on their design efficiency; for example, cooling load optimization is assessed based on floor area/tonnage load for residential and commercial building types separately for different climatic zones. Passive design features are encouraged to adopt in order to reduce the thermal load as well as cooling energy consumption. Socio-behavioural aspects are introduced in this system, such as limiting the floor area per capita, avoiding use of private vehicles, provision of rest rooms for service staff, and encouraging organic farming within the site.

Several upgradations have been done in the latest GRIHA version 2015, which would require quantification of performance of low-impact designs using simulation tools to encourage more passive design features. Some of these features include solar insolation analysis with respect to building massing and adjacent buildings/tree cover; limiting exposed wall areas on the east and west orientations and computational fluid dynamics (CFD) analyses for ensuring cross-ventilation in naturally ventilated and mixed-mode buildings. This version also introduced envelope peak heat gain thresholds based on the research carried out at TERI; EPI figures have been revised and made more stringent which is required as the system advances. It mentions flexible sustainable construction management in a separate section to make sure green practices are implemented on site. Adaptive thermal comfort model has been introduced based on CEPT University's IMAC study which provides threshold of comfortable indoor temperatures for different cities across the country. This model when implemented widely would have a larger environmental footprint in terms of cooling energy consumption. Thermal, visual, and acoustical comfort issues have been mentioned inclusively to encourage occupant's overall comfort and to minimize conflicts in the solutions provided under each comfort aspect. TERI has been carrying out indoor air quality studies and based on these studies, guidelines are being incorporated in the latest GRIHA versions. Occupant comfort is an important criteria and is gaining importance as it ensures productivity and optimizes personnel/ non-building operational costs.

Coming to GRIHA for large developments (GRIHA LD), almost all the upcoming institutional campuses in the country for IITs, IIMs, NITs, AIIMS, and Central Universities are registered with this rating system. This system is applicable for large mixed use townships, institutional campuses, hospital-cum-medical colleges, resorts, and special economic zones spread across site area ≥50 ha and/or having built-up area ≥150,000 sq. m. The unique feature of this system is to quantify the impact on a relative scale from an undeveloped site to the developed campus. This system mentions a few basic requirements, such as carrying capacity of site to limit development density, carbon footprint of site development to minimize on-site vehicular pollution, and increase vegetation requirement per capita. A GRIHA LD project gets evaluated based on both quantitative aspects to ensure self-sufficiency of resources, such as energy, water, and solid waste as well as the qualitative aspects for overall development quality. Various calculators are being developed based on research activities carried out at TERI for assessing urban heat island impact, campus level energy, and water footprint.

GRIHA rating system is able to spread its market in about 24 states in the country including Andaman and Nicobar islands. It is encouraging to see that there are about 10 projects registered from the Himalayan states which fall under cold climate. The technical team of GRIHA is now in the process of developing compliance criteria to meet specific requirements of this region.

The GRIHA Council along with the Sustainable Development Outreach and Youth Education division at TERI has also developed a rating system for schools (GRIHA Prakriti) with a vision to promote green practices among the future citizens of the country. This rating system is applicable for existing school buildings whereas the other three are only for new developments. It is undeniable that buildings are where we spend most of our time. The younger generations have to be educated on green building practices in the current lifestyle while responsibility of their prior generation increases to ensure global sustainable development.

GRIHA is continuously evolving—the strength of which is being variously applied and policy-related research carried out at TERI. The aspiration of the upcoming versions is that they deal with the aspects of climate-resilient housing in highly vulnerable areas as well as monetary benefits that a productive indoor environment of a commercial green building provides. EF

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EXPLORING CLEAN ENERGY OPTIONS

for Improved Agri-Food Value Chain in India

The history of agriculture in India dates back to the *Rigveda*. Despite being an agricultural-based economy, the agriculture sector still remains less explored in India. Each component of the agri-food value chain provides immense opportunities for research and innovation through inclusive and interactive approach. In this article, **Radhika Sharma** and **Astha Gupta** present an overview of the existing barriers as well as opportunities for clean energy applications in the agriculture sector.

Agriculture is the most common practice done since ages for the development of human civilization. It involves the use of natural resources such as plants to produce commodities including food, fibre, forest products, horticultural crops, and their related services to sustain and enhance human life. In India, about 60 per cent of the population including several million small farming households is dependent on agriculture as a principal income source. The net sown area in India is about 140.8 million ha wherein only about 37 per cent of net sown area is under irrigation and 67 per cent is predominantly rain-fed. Agriculture remains the second highest energy consumer and accounts for 18.03 per cent of the total energy consumption in India. Energy use in this sector is in the form of diesel and electricity for operation of mobile and stationary equipment and off the farm for the manufacture of inputs, such as fertilizers and pesticides. Besides energy, water is an essential component in the agriculture sector and is largely (approximately 80 per cent) used in the irrigation sector followed by domestic