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Dear Readers,

The use of renewable sources of energy like solar, wind, hydro in meeting our day to day energy requirements including electricity is now a known phenomenon and about 11.5 per cent electricity generating installations are from renewables in our country. Renewable energy contributes to mitigate the rapid degradation of the environment. Science has played a stellar role using innovative technology to discover new renewable energy sources, like fuel cell, biofuel, geothermal, ocean thermal energy and electric battery operated units, making renewable energy usable for everything from complicated processes to common place activities. The development of new sources of energy, although, at an initial stage, yet has an enormous potential. The Government is making efforts to make it commercially viable.

Amongst new resources, geothermal energy, hydrogen energy, fuel cell technology, biofuels, electric vehicles are the prominent areas where a breakthrough is expected shortly. In this context, the present issue has been prepared on new renewables. This issue of Akshay Urja promises its readers a wealth of information on new technologies with contributions from India's best known scientists and people who have been involved with current technology which is trying to bridge the gap between knowledge and the inspiring vision of setting the world free from sole dependence on fossil fuels, and the blight of pollution and environment degradation. The features on evolution of geothermal energy, geothermal scenario in India, ocean thermal energy with information on harnessing ocean energy in the form of waves, currents, and tides and how ocean thermal energy conversion (OTEC) can be used as a technology that utilises temperature differences to extract energy from the oceans have been presented. The areas such as electric vehicles, hydrogen energy and fuel cell technology which have proven to be by far path breaking, have been covered in an interesting manner.

I am sure that readers will find it informative, useful and interesting. Please do send your observations and critical comments about this issue. I wish all our readers a happy reading!

ARUN K TRIPATHI
<aktripathi@nic.in>
We wish to receive Akshay Urja, the bi-monthly newsletter in order to create awareness regarding renewable energy resources in our State especially in the region of Hyderabad-Karnataka. The newsletter contains very valuable and detailed information about new projects, functions, scheduled plans, features, research, international news etc., pertaining to the new and renewable energy sector. Hence, it will be indeed helpful for us to share the information with the rural people in addition to creating awareness about new and renewable energy resources.

Deputy General Manager
Karnataka Renewable Energy Development Ltd.,
Gulbaraga, Karnataka

We are writing to you from the Dr. Ambedkar Institute for Handicapped, U.P. It is the only Institute in North India (designed barrier-free) that imparts technical education to handicapped students, awarding degrees in computer science, electronics, chemical engineering, IT and Biotechnology since 2004. The Institute will be grateful to you for accepting our request of sending us the newsletter on a regular basis for the welfare of the students.

Dr. Gaurav Chandra
Director, Dr. Ambedkar Institute of Technology for Handicapped, Kanpur

I am pleased to know that the Ministry of New and Renewable Energy brings out such an interesting and informative newsletter like Akshay Urja. I am writing from the Pinkcity Engineering College and Research Centre, Jaipur. We would like to receive Akshay Urja on a regular basis, so that our students and faculty can know and learn the value of energy conservation and renewable energy sources along with the capacity of various non-conventional power plants. We look forward to your reply.

Prof. M. Lalwani
Pinkcity Engineering College and Research Centre, Jaipur, Rajasthan

I would like to introduce myself as an Asst. Manager (Environment) working in Kolkata. I am very interested in new and renewable energy sources and I find that the Akshya Urja magazine is very informative and useful for me. I wish to subscribe to your magazine. You are requested to please suggest the procedure and formalities for the same.

Rohan Kumar Mehto
Kolkata, West Bengal

I am passionate about renewable energy studies. I have been reading your newsletter for the last two months and I am delighted with the knowledge that I have gained. I want to extend my heartfelt congratulations and thanks to the editor and the entire team of Akshay Urja for their in-depth analysis related to the field of renewable energy and for compiling the newsletter so wonderfully. I would also like to express my deep interest to be included in your group of niche readers of Akshya Urja and would like to subscribe to the newsletter.

Pratik Mor
Ber Sarai, New Delhi

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A detailed study of the use and applicability of geothermal energy in the Indian context.

Power from a biogas plant in the residential school which has helped an institute to meet their needs in everyday life from cooking to running various machines.

Today’s fast world is overly dependent on energy to fulfill requirements related to daily life. Compressed biogas comes as an efficient and cost-effective method to meet this need.
Kolkata Gets a New Renewable Energy College

Kolkata can now boast of a renewable energy college that opened in the city in January 2012. The college is located off EM Bypass at Maduridaha. Students passing out from the college receive a diploma jointly certified by the Indira Gandhi National Open University (IGNOU) and the Technical Education Department of the State of Queensland, Australia. The college is the brainchild of renewable energy expert and Ashden award winner S P Gon Chaudhuri, who is presently Advisor to the state government’s power department. “Students who pass out from this college will be recognised as renewable energy engineers,” stated Gon Chaudhuri, who will head the college as its chairman.

India, China Focussing on Renewable Energy Sources: WEF

India, China and South Korea are increasingly focussing on renewable energy sources, including wind and solar, as potential growth sectors for their economies, as per the World Economic Forum report released on 9 March 2012.

However, the report, Energy for Economic Growth - Energy Vision Update 2012, which provides a framework for understanding the larger economic role of the energy industry, added that the higher costs of these technologies create trade-offs that must be considered.

“Energy prices will always be volatile and thus represent a challenge for long-term economic planning,” said Kenneth Rogoff and Thomas D Cabot, Professor of Public Policy and Professor of Economics, Harvard University. “The question is how to make this volatility less economically damaging,” added Rogoff, who is part of the WEF advisory board. While multiplier effects for solar and wind energy were lower during operation, their contribution during the construction phase reached as high as 3.3 indirect jobs per energy job. “The energy industry is unique in its economic importance and has the potential to be a tremendous catalyst for job creation and sustainable growth without harming the sector’s overall performance,” said Chairman Daniel Yergin of IHS CERA, which has partnered in the preparation of the WEF report. The energy industry thus has the ability to generate significant contributions to GDP growth, the report said.

REC Raising New €100 mn Loan

The Rural Electrification Corp. Ltd. (REC) is set to raise €100 million (Rs. 656 crore) from Germany-based KfW Bankengruppe for financing renewable energy projects in India at concessional interest rates. The REC has sanctioned loans worth Rs. 50,000 crore and disbursed loans estimated at around Rs. 25,000 crore in the current fiscal (2012-13). “The REC is borrowing from a foreign lender to tide over the acute shortage of funds facing power companies in India. Also, funds raised from global markets are cheaper, given the high interest rates in India” said R Sharma, CMD, REC. The REC and the Power Finance Corporation of
India which accounts for 60 per cent of lending to the power sector, have formulated guidelines for lending to renewable energy projects for the first time. India’s power sector, already struggling with fund shortfalls, will need an investment of $400 billion during the 12th Five-Year Plan (2012-17).

India’s Wind Energy Potential is Over 2,000 GW

According to a recent study by the US based Lawrence Berkeley National Laboratory, the real wind energy potential of India is well over 2 million MW. After reassessing the land that can be used for wind power development, so as to take into account previously excluded lands, Lawrence Berkeley concluded that the true potential of wind energy in India is between “20 and 30 times higher than the current official estimate of 102 GW.” It was previously thought that only 2 per cent of land in windy areas could be used for putting up wind power projects. The study looked at wind speeds at heights of 80 m, 100 m and 120 m and has found that nearly 1,629 sq km of area is available for setting up wind turbines at a height of 80 m, with a plant load factor (PLF) of more than 25 per cent. The cost of wind power is now comparable to that from imported coal and natural gas based plants, and wind can play a significant role in addressing energy security and environmental concerns in a cost effective manner.

Committee on Renewable Energy Set Up

The government has set up a committee to suggest legislative and policy changes to speed up capacity addition from renewable power sources like wind, biomass and the Sun. The committee will be headed by a senior official from the Power Ministry and include representatives from the Ministry of New and Renewable Energy, power distribution companies (discoms), Central Electricity Regulatory Commission, electricity regulatory commissions from renewable resource-rich states like Tamil Nadu, Gujarat and Rajasthan and power project funding agencies, like Power Finance Corporation (PFC) and Rural Electrification Corporation (REC).

The committee’s terms of reference include suggesting legislative changes to make it binding for discoms to comply with the renewable purchase obligation (RPO). It is also mandated to outline measures to penalise discoms in case of violation of the obligation. The panel also has the mandate to suggest amendments to the Electricity Act 2003 to empower the regulators to frame innovative market instruments.
like renewable energy certificates (REC) to facilitate development of the renewable power market.

www.financialexpress.com
28 March 2012

**Fedders Lloyd to Expand Wind Energy Equipments facility at Bharuch**

The Lloyd Group owned Fedders Lloyd plans to invest Rs 200 crore for expanding its newly built manufacturing facility for wind turbine towers, heavy precision fabrication and machining facility in Bharuch district, Gujarat. The group commissioned the first phase of the unit and it has already acquired land for the phased expansion.

Commenting on the project commissioning, Fedders Lloyd CMD Brij Raj Punj said that renewable energy represents the next big frontier in the technology industry and the new facility is a testament to Fedders Lloyd’s commitment to contribute towards India’s growing energy revolution in India.

The Union Minister for New and Renewable Energy, Farooq Abdullah and Gujarat Chief Minister Narendra Modi inaugurated the new facility of Fedders Lloyd on 13 April 2012. The plant is capable of manufacturing wind turbine powers up to 3 MW and heavy precision fabrication of components up to 80 tonne.

Established in 1957, Fedders Lloyd is engaged in executing turnkey projects in the areas of energy, infrastructure and climatic control equipment with manufacturing facilities at Noida, Sikandrabad and now Bharuch.

www.financialexpress.com
28 March 2012

**Government Extends Popular Accelerated Depreciation Scheme for Wind Power Producers**

The government has decided to extend the popular accelerated depreciation incentive for wind power producers beyond 31 March this year, when it was due to be terminated, as the alternative generation based schemes have not found enough takers. Power producers can opt for either of these incentive schemes, and since as many as 70 per cent have opted for accelerated depreciation, an overwhelming majority of the companies have been lobbying for extension of this scheme which provides subsidies for setting up wind-generated power plants.

At the same time, the generation-based incentives, introduced in 2009, have fallen way short of the government’s target of 4,000 MW, yielding just 1,500 MW so far.

Officials and industry persons reacted to the news positively. “We have asked the Finance Ministry to let accelerated depreciation continue as it will help us achieve the earlier missed targets” said GB Pradhan, Secretary, Ministry of New and Renewable Energy. “Accelerated depreciation has been a major support to industries looking for captive power capacity for energy security and to freeze power costs, making the sector even more globally competitive,” said the official spokesperson of Suzlon, the leader in the domestic market. V Subramaniam, Secretary General of Indian Wind Energy Association, said the extension of the scheme will prove to be a boon to companies. “This will help attract more orders”, said Subramaniam, calculating an investment of Rs 15,000 cr at an estimated installation of 3,000 MW of wind-generated power this year.

www.articles.economictimes.indiatimes.com
27 March 2012

**Hybrid Guide Lights for Fishermen at Night**

The Fisheries Department has decided to install 10 hybrid guide lights in the fishing hamlets of coastal Tamil Nadu to enable fishermen to reach their destinations at night, with ease.

Fishermen set out for sail, keeping major lighthouses as an identification mark. Due to lack of proper lighting system and high winds, they often land a few kilometres away from their destinations. Hence, they sought the help of Fisheries Department.

Based on reports of the cost effective hybrid system installed at Tamil Nadu Development Corporation’s Raindrop Boat House in Mudaliarkuppam, three years ago, the officials of the Fisheries Department approached Coimbatore-based Viviann Electric. The firm developed three devices which have been functioning at Panaiyur Chinnakuppam in
Kancheepuram district, Tranquebar near Nagapattinam and Somanathan Pattinam in Thanjavur district since January 2011. The device uses both solar and wind energy. These solar and wind hybrid guide lights comprising LEDs with 40 watts capacity and 500 watts wind generator, are visible several kilometres from the shore. Sources stated that Coast Guard officials too have started using them as a landmark.

www.thehindu.com 26 March 2012

Rice Husk, Solar Energy to Solve Power Issues

If all goes well, rice husk and solar power - two very unlikely partners - will together provide rural India with a twin solution to its problems of power shortage and lack of storage for agriculture produce. What’s more, the evolving system promises zero emission of pollutants as well.

The government’s Solar Energy Centre, New Delhi, has managed to make use of rice husk and solar power, both of which are being wasted at present, to come up with a technological marvel that would prevent wastage of food grains in rural India. The rice husk is burnt to produce enough energy for powering a turbine and producing electricity. As of now, there are 60 mini-rice husk powered electricity plants that light 25,000 households in different parts of the country. The emission from the rice husk plants is coupled with energy generated by solar thermal plates to run a cold storage with a capacity of 15 tonnes. The project, undertaken in collaboration with Thermax and The Energy and Resources Institute, is past the experiment stage and is set to be rolled out in rural India.

www.hindustantimes.com 29 March 2012

India to be a Global Sourcing Hub for Solar Projects

AREVA, the US-headquartered renewable energy subsidiary of the French nuclear energy group, AREVA, has an ambitious plan to tap the growing solar market in India as a technology provider. William D Gallo, president and chief executive officer, has promised to make India a hub to source solar technology for their international operations. Gallo informed that India enjoys 250 to 300 sunny days a year and is, therefore, a potentially privileged location for solar power plant projects. The company has also been awarded a contract by Reliance Power to set up a 250 MW project in Rajasthan.

The AREVA group aims to position itself as a strategic player in the development of renewable energy sources. India will be a global sourcing hub for solar projects, remarked Gallo. He said that as a technology provider, AREVA will source most of the steel and glass from the domestic market, and has plans to set up a large number of plants in India. Besides, there is availability of the skills required for assembling and for this they will rope in local contractors. Gallo added that the Concentrated Solar Power (CSP) systems used by AREVA are suited for a variety of power plants from 50 MW to several hundred MW, as well as a diverse range of industrial steam applications and that they are cost effective, land conservative and water efficient.

www.hindustantimes.com 16 April 2012

India’s Installed Power Generation Capacity Crosses 2 Lakh MW Mark

India's installed total power generation capacity has crossed the 2 lakh MW mark with the commissioning of a 660 MW unit of a power plant in Jhajjar in Haryana. The total installed capacity in the country has now reached 2,00,287 MW, per an official press release. This includes 1,32,013 MW capacity in the thermal sector, 38,991 MW in the hydro sector, 4,780 MW in the nuclear sector and 24,503 MW in the renewable energy sector. At the end of the 11th Plan, i.e. on 31 March 2012 the total installed capacity stood at 1,99,627 MW. There was a capacity addition of 54,964 MW in the 11th Plan period, up 159 per cent over the 10th Plan period when 21,180 MW capacity was added. During the Ninth Plan, the capacity addition stood at 19,010 MW. In 2011-12, a capacity of 20,501 MW was added, out of which 5,482 MW was added in March 2012 alone, the release added.

www.netindian.in 14 April 2012
**Smart Paint Could Revolutionise Structural Safety of Bridges, Mines and More**

An innovative low-cost smart paint that can detect microscopic faults in wind turbines, mines and bridges before structural damage occurs is being developed by researchers at the University of Strathclyde in Glasgow.

Traditional methods of assessing large structures are complex, time consuming and use expensive instrumentation, with costs spiraling into millions each year. However, the smart paint costs just a fraction of the cost and can be simply sprayed onto any surface, with electrodes attached to detect structural damage long before failure occurs. Dr Mohamed Saafi, of the University’s Department of Civil Engineering, said: “The development of this smart paint technology could have far-reaching implications for the way we monitor the safety of large structures all over the world.”

**Nanotrees Harvest the Sun's Energy to Turn Water Into Hydrogen Fuel**

Electrical engineers at the University of California, San Diego are building a forest of tiny nanowire trees in order to cleanly capture solar energy without using fossil fuels and harvest it for hydrogen fuel generation. Reporting in the journal, Nanoscale, the team said nanowires, which are made from abundant natural materials like silicon and zinc oxide, also offer a cheap way to deliver hydrogen fuel on a mass scale.

The trees' vertical structure and branches are key to capturing the maximum amount of solar energy, according to Deli Wang, professor in the Department of Electrical and Computer Engineering at the UC San Diego Jacobs School of Engineering. In the long run, what Wang’s team is aiming for is even bigger: artificial photosynthesis. In photosynthesis, as plants absorb sunlight they also collect carbon dioxide (CO₂) and water from the atmosphere to create carbohydrates to fuel their own growth. Wang’s team hopes to mimic this process to capture CO₂ from the atmosphere, reducing carbon emissions and converting it into hydrocarbon fuel.

**Germany Could Become Storage Technology Hotspot**

During the International Summit for the Storage of Renewable Energy, Germany’s Environment Minister, Norbert Röttgen spoke about market incentives for storage systems. These, he said, are important for the development of market applications. He went on to tell the audience of over 300 experts, from 28 countries, that the immediate task is to develop renewable energy and energy efficiency technologies, and integrate them into the market. Eicke Weber, spokesman for the Fraunhofer Energy Alliance and head of the Fraunhofer Institute for Solare Energy Systems (ISE), during his presentation asserted, "Energy storage is part of a paradigm shift in renewable energy adoption and usage. Storage at its basic is about being able to use harvested renewable energy produced at a very low cost exactly when we need it." He said that there is a wide range of storage technologies, which will create an important role for energy storage systems in Germany’s future. According to Weber, the country is particularly well-positioned to become a hotspot for energy storage technologies, due to plans to phase out nuclear power and its clear goals on continuing the expansion of the deployment of fluctuating renewable energy.

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www.sciencedaily.com
7 March 2012

www.pr-magazine.com
13 March 2012

www.pv-magazine.com
13 March 2012
large amounts of sunlight onto a small area. This light is converted to heat, which generates electricity. But harsh desert conditions in parts of the MENA region generate large amounts of airborne dust which collects on the solar panels used in CSP systems, reducing their efficiency. They need regular cleaning, which consumes large amounts of water.

Now, the Masdar Institute of Science and Technology says it will work with Siemens AG to develop coatings using water-repellent materials, commonly used to manage oil spills. These materials force water droplets to form beads that then trap dust, meaning that less water would be needed to keep the panels clean.

Matteo Chiesa, Associate Professor of Mechanical Engineering at the Masdar Institute said that the team is also developing a modelling tool that will incorporate weather data, to predict how often the panels will need cleaning. He also added that the field tests are underway to test the coating and predictive tool, and the adapted solar panels could reach the market within five years.

Abu Dhabi is teaming up with a global electronics company to develop better coatings for solar panels to make them cheaper and easier to keep clean in desert conditions. The Middle East and North Africa (MENA) region stands to benefit from concentrated solar power (CSP) – a technology that uses lenses or mirrors to focus

Scotland will be able to generate all its domestic electricity using renewable methods by 2020, the government has confirmed. However, it will be a challenge to reach the target and green energy generation will need to be supported by at least 2.5 GW from thermal power units that will be increasing their carbon capture and storage rates. The government also aims to completely remove carbon from electricity generation by 2030, under plans outlined in the Electricity Generation Policy Statement (EGPS), which has just been released.

Fergus Ewing, Scotland’s Energy Minister, says, “We know there is doubt and scepticism about our 100 per cent renewables target, and the financial and engineering challenges required to meet it. But we will meet these challenges. I want to debate, engage and co-operate with every knowledgeable, interested and concerned party to ensure we achieve our goals.” The plans mean there will be no need to build any new nuclear power stations in Scotland. By 2020, the government aims to support local and community ownership of at least 500 MW of renewable electricity and heat energy. It also plans to reduce final energy consumption in Scotland by 12 per cent and complete full carbon capture and storage at power stations from 2025-2030. In the related ‘The Power of Scotland Secured’ document, green campaigners ‘Friends of the Earth’ commissioned a report saying that by 2030 renewable methods could provide enough electricity for all of Scotland’s energy needs plus 85 per cent extra for export.
Hydrogen Energy and Fuel Cell Technologies
Recent Developments and Future Prospects in India

Energy security is a major challenge that needs imaginative and innovative solutions for a country like India. Therefore, options for diversification of fuels and energy sources need to be pursued vigorously to enhance the economic growth rate for socio-economic development.

M R Nouni

The growing concern about depleting oil reserves, harmful effects of greenhouse gas emissions and the necessity to reduce emissions from power plants and vehicles are some of the key factors encouraging the development of new and renewable energy technologies. Hydrogen: the zero carbon fuel, excels in comparison to other fuels including bio-fuels, with regard to first the decrease and then the elimination of the effect of climate change. Thus, hydrogen is a clean energy carrier with potential to replace liquid and gaseous fossil fuels in the coming decades. In recent years, notable progress has been made globally for the development and demonstration of hydrogen energy and fuel cell technologies. Hydrogen can store and deliver usable energy, but it doesn’t exist by itself in nature. It must be produced from compounds that contain it - using available resources - natural gas, coal and nuclear; biomass and other renewables including solar, wind, hydro-electric, or geothermal energy. This diversity of being able to use diverse energy sources makes hydrogen a promising energy carrier and important from the energy security viewpoint. Hydrogen is high in energy content as it contains 120.7 MJ/kg, which is the highest for any known fuel. However, its energy content on volume basis is rather low. This poses challenges with regard to its storage for civilian applications, when compared to storage of liquid fossil fuels.

With primary emphasis on energy security and environment improvement, various Research, Development and Demonstration (RD&D) activities on different aspects
Cover Story

of hydrogen energy that includes hydrogen production, its storage and applications for motive power and power generation through internal combustion engine and fuel cell based systems, have been pursued by academic institutions, Council for Scientific and Industrial Research (CSIR) laboratories, industry etc. with the support of Government of India, for more than two decades. As a result, laboratory scale prototypes have been developed and some of them include: (a) bio-hydrogen production using distillery wastes; (b) Proton Exchange Membrane (PEM) based electrolysers for hydrogen production through splitting of water and water-methanol mixture; (c) inter-metallic hydride with storage capacity upto 2.42 wt per cent; (d) liquid organic hydrides for hydrogen storage with storage capacity of about 6 wt per cent; (e) methanol reformer for production of hydrogen, which can be used in PEM fuel cells; (f) hydrogen catalytic combustion cookers; (g) hydrogen fuelled motor-cycles and three wheelers with hydrogen storage in metal hydrids; (h) hydrogen fuelled three wheelers with hydrogen storage in high pressure composite cylinders; (i) hydrogen fuelled internal combustion engine for stationary power generation; (j) phosphoric acid fuel cells with stacks up to 25 kW capacity; (k) PEM fuel cells with stacks up to 5 kW capacity; (l) UPS system based on PEM fuel cell; (m) fuel cell battery hybrid van; (n) hydrogen blended CNG (H-CNG) fuelled vehicles; etc. Use and applications of hydrogen are in the early demonstration stages in the country both for transport and for stationary power generation.

National Hydrogen Energy Road Map
With a view to accelerate the development of hydrogen energy sector in the country, a National Hydrogen Energy Board, which included all the stakeholders, was constituted in 2003. They created a National Hydrogen Energy Road Map that provides the broad pathway to be followed for development and introduction of hydrogen energy technologies in the country. For achieving the overall growth of the entire hydrogen energy sector, the Road Map suggested ambitious targets for transport sector and power generation for the period up to 2020. It also emphasised the need for taking up a wide ranging R&D programme in the country including eight projects in mission mode relating to (a) clean coal gasification technologies for hydrogen production; (b) hydrogen production through biological sources; (c) hydrogen production through renewable energy sources; (d) hydrogen production through nuclear thermo-chemical water splitting method; (e) hydrogen storage in hydrides; (f) hydrogen storage in carbon nano-structures; (g) development of internal combustion (IC) engine for hydrogen fuel; and (h) development of PEM and solid oxide fuel cell (SOFC) technologies.

Efforts made during 11th Plan
Hydrogen energy and fuel cell activities in the country received an impetus after the acceptance of the National Hydrogen Energy Road Map in 2006. From 2006-07 onwards a total of 54 new RD&D projects, of which 38 projects in the area of hydrogen, its storage and applications and 16 projects related to different fuel cell technologies are being supported by the Ministry of New and Renewable Energy (MNRE). The extent of the support provided to hydrogen energy and fuel cell activities is clear from the fact that out of 169 new RD&D projects supported by the MNRE during the 11th Plan Period (2007-08 to 2011-12), 44 projects(26 per cent) were related to hydrogen energy and fuel cells. In terms of the total financial support provided by the MNRE during the 11th Plan Period, hydrogen energy and fuel cell projects were provided with a budget of about Rs. 118 crore out of the total RD&D support of about Rs. 507 crore.

Hydrogen production
It is pertinent to note that a large number of projects concerning hydrogen production, have been sanctioned during the 11th Plan and are shown in Fig. 1. Further, for meeting the requirement of hydrogen up to 2020, the National Hydrogen Energy Road Map had suggested

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Hydrogen can be produced using locally available resources including natural gas, coal and nuclear, biomass and other renewables including solar, wind, hydro-electric or geothermal energy.

![Fig 1. Sector wise distribution of sanctioned RD&D Projects related to Hydrogen Energy and Fuel Cells during the 11th Plan](image-url)
The National Hydrogen Energy Road Map provides the broad pathway to be followed for development and introduction of hydrogen energy technologies in the country.

different processes as shown in Fig. 2. In order to meet the immediate requirement of hydrogen for transport and power generation applications, it was suggested to tap by-product/spare hydrogen available in industries like chlor-alkali industries, fertiliser plants and petroleum refineries. A study conducted by the University of Petroleum and Energy Studies estimated a theoretical surplus of 0.0313 MMT, out of a total hydrogen generation capacity of 0.0732 MMT from chlor-alkali units during 2007-08. No surplus hydrogen is available in petroleum refineries and fertiliser plants. As per information compiled by the Alkali-Manufacturers Association of India, hydrogen produced by 37 chlor-alkali units in India was about 666.29 million N cu m (0.0598 MMT) during 2010-11. About 86.39 per cent of it was being utilised for production of hydrochloric acid, as fuel for captive use sold after bottling it, in downstream units and other applications. Therefore, about 0.0081 MMT of surplus hydrogen was available from chlor-alkali units during 2010-11. However, it seems that the amount of surplus hydrogen from chlor-alkali units is progressively reducing after analysing the hydrogen consumption pattern for the years 2008-09, 2009-10 and 2010-11.

A demonstration project for on-site hydrogen production using alkaline electrolyser of 5 N cu m/hr capacity, blending it with compressed natural gas and dispensing of H-CNG was commissioned at Dwarka in New Delhi by the Indian Oil Corporation Limited (IOCL) in March, 2009. A similar unit was installed by IOCL in its R&D Centre at Faridabad in 2005. These facilities are being currently used for dispensing H-CNG fuel in some demonstration vehicles. The Electrical Research and Development Association (ERDA), Vadodara has developed a prototype demonstration project for wind hydrogen based stand-alone electrical generation. Under this project, 2x5 kW small wind turbines have been used to meet the electrical energy requirement of a load either directly through a battery bank or through a gen-set, which used hydrogen as a fuel produced by an electrolyser operated by direct current (DC) drawn from the battery bank. With a view to generate hydrogen from solar energy, a hydrogen production and dispensing facility is scheduled to be set up at the Solar Energy Centre (SEC), Gwalpahari using PV generated electricity for operating an electrolyser. The demonstration project, being implemented by the University of Petroleum and Energy Studies (UPES), Dehradun is likely to be commissioned by 2013-14. For hydrogen production through gasification of biomass, one project each is being implemented by the Indian Institute of Science (IISc), Bangalore and the National Institute of Technology (NIT), Rourkela. The IISc is working on the development of the oxy-steam gasification unit using an open top downdraft gasification system for hydrogen production rate of about 0.1 kg/kg biomass at various steam-to-biomass ratios. The NIT, Rourkela will be developing a bench scale fluidised bed gasifier of 5 kW capacity for hydrogen production rate of about 0.09 kg/kg of feed stock.

A pilot plant of 800 litres capacity for bio-hydrogen production was installed at Indian Institute of Technology (IIT) Kharagpur under a project that concluded in 2007. Hydrogen yield was observed to be 5.5 moles of hydrogen per mole of sucrose after 25 hours of fermentation, which amounted to about 2.4 cu m of hydrogen production per day from the reactor (the average hydrogen production is in the range of 3-5 volumes per day per volume of the reactor). In a mission mode project, under implementation from 2009 to 2014, IIT Kharagpur in association with Allahabad University, Banaras Hindu University (BHU), Indian Institute of Chemical Technology (IICT) Hyderabad, Jawaharlal Nehru Technological University (JNTUH) Hyderabad, and The Energy Research Institute (TERI), New Delhi would be designating, developing and installing three 10 m³ capacity pilot demonstration plants with...
hydrogen generation capacity of 30,000 to 50,000 litres per day. This project would aim at making bio-hydrogen production commercially viable by way of selection of suitable organic waste as substrate; development of suitable consortia for the process; use of thermophiles to avoid the sterilisation of the waste materials; and development of an integrated (two stage fermentation) process.

The IICT has undertaken work relating to catalyst development and bench scale reactor development for hydrogen production studies from biomass derived glycerol during 2008-11. The bench scale reactor is being scaled up for the development of a pilot demonstration plant of 2 N cu m/hr capacity of hydrogen production by IICT. The Central Institute of Mining and Fuel Research (CIMFR), Dhanbad developing a novel process for production of hydrogen from renewable and fossil fuel based liquid and gaseous hydrocarbons, by the non-thermal plasma reformation technique.

The Centre for Materials for Electronics Technology (C-MET), Pune and IICT are working on developing processes for decomposition of hydrogen sulphide for production of hydrogen by photo-catalytic and non-thermal plasma assisted methods respectively. For splitting water using solar energy directly, which is dubbed as the ultimate and sustainable method for hydrogen production, Institute of Minerals and Materials Technology (IMMT), Bhubaneswar; IICT and Yogi Vemana University, Kadapa are some of the institutions that are engaged in carrying out R&D work in India.

**Hydrogen Storage**

Hydrogen storage remains a major problem for the development and viability of hydrogen-fuelled vehicles and is considered by many to be the most technologically challenging aspect for achieving a hydrogen-based economy. As per the experts, on-board hydrogen storage capacity in the range of approximately 5–13 kg is required to enable a driving range of about 500 kms for typical automotive vehicles using fuel cell power plants. Presently hydrogen can be stored in three forms; gaseous, liquid or as a solid combined with a metal hydride. The most suitable storage method is dependent upon safety aspects, environmental issues, economic criteria and the end-use of hydrogen.

The R&D work carried out so far in the country has been focussed on metal hydrides, inter-metallic hydrides, complex hydrides, liquid organic hydrides etc. While three R&D projects were completed during 11th Plan (Fig 3), seven new R&D projects were sanctioned during this period in the area of hydrogen storage (Fig 1). The completed projects were related to synthesis and evaluation of complex hydrides; development of liquid organic hydrides; and theoretical investigation on ‘likely to be favourable factors’ of helical carbon nano-tubes for enhanced hydrogen absorption undertaken by IIT, Mumbai; National Environmental Engineering Institute (NEERI), Nagpur and Thiagarajar College of Engineering, Madurai, respectively. The NEERI identified and tested a catalyst for dehydrogenation of cyclohexane and methylcyclohexane. Hydrogen storage capacity for the process was found to be 6.1- 6.8 wt per cent.

With a view to achieve about 5 wt per cent storage capacity in hydrides and carbon materials with cycle life of more than 1000, one mission mode project each is being implemented by BHU, Varanasi and IIT Madras, Chennai. Non Ferrous Materials Technology Development Centre, Hyderabad and NIT, Tiruchirappalli are working on different aspects of magnesium hydride material. The IIT,
Guwahati is engaged in development of a metal hydride based hydrogen storage device.

**Use of Hydrogen in Engines and for Thermal Applications**

Efforts related to use of hydrogen as fuel have been mainly focused on development of internal combustion engines by modifying petrol, diesel and gaseous engines to operate with hydrogen. To begin with, existing spark ignited engines were modified to operate with hydrogen as a fuel. Prototypes of such engines are small single cylinder engines. A single cylinder four stroke, spark ignited, air cooled 5 hp engine was modified to operate with hydrogen and integrated with a 2.5 kVA alternator by IIT, Delhi for power generation for stationary applications. The learnings from this effort helped IIT, Delhi develop a hydrogen fuelled engine for a three wheeler in association with Mahindra and Mahindra (M&M). In addition, petrol driven motorcycles and three wheelers have also been modified to operate with hydrogen as a fuel by BHU, Varanasi.

Blending of hydrogen with CNG was considered to be the best strategy for not only introduction of hydrogen in some form in vehicles under Indian conditions but also for gaining experience about production, storage, dispensing and application of hydrogen as the infrastructure for CNG was already available in some parts of the country. On acceptance of the National Hydrogen Road Map, one of the earliest projects taken up for implementation related to the use of hydrogen (up to 30 per cent) as fuel, blended with CNG in an internal combustion engine. Under this project, being implemented by the Society of Indian Automobile Manufacturers (SIAM) and R&D Centre of IOCL, two three wheelers, two cars, two mini buses and one cargo vehicle have been developed by five automobile companies i.e. Ashok Leyland Limited, Bajaj Auto Limited, M&M, Tata Motors and Volvo Eicher. Based on the performance and emission tests undertaken by IOCL, it was decided that blending of 18 per cent hydrogen by volume with CNG is the optimum blend to be used in the vehicles included in the project. Currently, these vehicles are undergoing field endurance testing (30,000 kms for three wheelers and 50,000 kms for other vehicles) between Faridabad and Dwarka, New Delhi as the facilities for supply of H-CNG exist at R&D Centre of IOCL at Faridabad and Dwarka, New Delhi. The project would be completed during 2012 and may pave the way for introduction of more H-CNG fuelled vehicles on Indian roads.

In order to study the impact of using hydrogen - diesel and hydrogen-straight vegetable oil (SVO) in dual fuel mode on performance and emissions of engines, two projects are under implementation. One project is being implemented by M&M in technical collaboration with Saskatchewan Research Council (SRC), Canada for development and demonstration of a sports utility vehicle using hydrogen along with diesel. Under another project, the University of Petroleum and Energy Studies (UPES) is developing a stationary engine for using hydrogen with SVO.

The M&M in association with the IIT, Delhi has developed 15 three wheelers under a project named ‘DELHY-3W’ which was supported by the United Nations Industrial Development Organisation (UNIDO) through the International Centre for Hydrogen Energy Technologies (ICHET), Istanbul, Turkey (Fig. 4). This project was supported in March, 2009 with IIT Delhi; M&M; Air Products / INOX Air Products; and India Trade Promotion Organisation (ITPO) as project partners.
Under this project, 15 hydrogen fuelled three wheelers are being demonstrated at New Delhi currently. Hydrogen is stored in a compressed gaseous form in composite cylinders. Limited field trials have shown that the hydrogen fuelled three wheelers are giving around 85 km per kg of hydrogen consumed. The facilities for transport, storage and dispensing of hydrogen has been provided and managed by the Air Products. Under another project, BHU Varanasi is engaged in development of about 10 hydrogen fuelled three wheelers with hydrogen storage in metal hydrides instead of in the gaseous form in a pressure vessel.

With a view to develop a multi-cylinder hydrogen fuelled engine that can be used in a bus, a mission mode project is under implementation by IIT, Delhi in association with M&M. The Annamalai University is working on lean limit extension for spark ignited direct injection engine through on-board non-thermal plasma conversion for hydrogen production. Also IIT, Kanpur is undertaking experimental investigations on combustion characteristics and emission reduction of laser fired hydrogen engine and is engaged in design and development of hydrogen gas burner for industrial applications.

Fuel Cell
The focus of R&D on fuel cells in India is on different types of fuel cells namely polymer electrolyte membrane fuel cell (PEMFC), phosphoric acid fuel cell (PAFC), direct methanol fuel cell (DMFC), direct ethanol fuel cell (DEFC), solid oxide fuel cell (SOFC) and molten carbonate fuel cell (MCFC). The emphasis of research has been on further improvements in fuel cell related processes, materials, components, sub-systems and fuel cell systems.

Ten projects related to different aspects of fuel cell technologies were concluded during the 11th Plan period. Several R&D projects are under implementation with various universities of India.

Industry Driven Initiatives
The Indian automobile industry and telecom tower operators too have made efforts to use hydrogen for powering automobiles using IC engine as well as fuel cell technology and also for providing back up power for telecom towers using fuel cells. In addition to M&M, Tata Motors has developed a fuel cell bus under a project supported by the Council of Scientific and Industrial Research (CSIR) and are planning to develop and demonstrate 10 fuel cell buses in the future. Idea cellular, a telecom tower operator has installed a PEMFC system to provide backup power to a telecom tower in Madhya Pradesh using hydrogen supplied from the nearby chlor-alkali unit (Fig 5). Such fuel cell systems would replace diesel generator sets, which in turn create environmental hazards.

Capacity Building
With a view of capacity building in hydrogen energy sector and as suggested in the road map, a National Centre of Excellence for Hydrogen Energy and Fuel Cells may be set up in the country. For this purpose, a detailed project report (DPR) on setting up of National Hydrogen and Fuel Cell Centre at Gwalphahari, Gurgaon has been prepared.

Prospects for Future
There is an urgent need to set up hydrogen production cum dispensing stations at suitable locations, especially for making operation of hydrogen fuelled vehicles possible. We may also see hydrogen fuelled vehicles for public transport, including three wheelers and buses using either IC engine or fuel cell technologies on Indian roads. This is highly realistic as the Indian automobile industry has already taken a lead in this direction. However, this would require notifying H-CNG as well as hydrogen as automotive fuels. Fuel cell based systems may be used for power generation to provide backup power for telecom towers and stationary power generation by using surplus by-product hydrogen from chlor-alkali units.

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The earth is a reservoir of heat energy most of which is buried and is observed during episodes of volcanic eruption at the surface. It also manifests as hot springs, geysers and fumaroles. Thermal springs have been known to occur the world over for centuries. This resource did not attract attention for energy development probably because not enough was known about its potential till the early twentieth century. Conventional sources of energy like coal, oil and wood are non-renewable and are likely to deplete with the passage of time or depth of exploration becomes cost prohibitive. Also these resources create inherent problems of environment degradation and imbalance in ecology. The ‘oil crisis’ of the 1970s, resulting in low supplies of oil from producing countries led to the need for exploring alternative sources of energy for power production and other industrial uses. One of the resources was geothermal energy i.e. energy stored in the earth’s crust.

Thermal springs have been a known phenomenon in India for centuries. People often visit these springs as a part of religious custom and belief considering the water to be ‘God’s Gift’ to mankind and capable of miraculous healing of skin and other rheumatic ailments like arthritis. However, all thermal springs oozing at the surface need not
necessarily have geothermal energy potential.

Schlagintweit (1862) and T. Oldham (1882), inventoried a total of 301 thermal springs in the Indian subcontinent. However, these studies were mostly in reconnoitory state wherein documentation of the thermal springs, their surface temperature and assessing the medicinal qualities were recorded. At many places, like Badrinath and Gangotri in Uttarakhand; Sohna in Haryana; Rajgir in Bihar; Bakreshwar in West Bengal and Ganeshpuri in West Coast, Maharashtra, temples have been built on thermal springs and the water has been channelised for public use. Systematic efforts to explore geothermal energy resources commenced in 1973 with the launching of the Puga geothermal project in Ladakh, J&K and gradually the exploration work was extended to cover Chhumathang in Ladakh, Parbati valley, Himachal Pradesh.; Sohna, Haryana; West Coast, Maharashtra and Tattapani, Sarguja in Madhya Pradesh. To achieve the objectives of this endeavour, geological, geophysical, geochemical, and drilling activities were carried out under an integrated programme with the Geological Survey of India (GSI) as the lead agency and executed with the collaboration of many national agencies, viz. National Geophysical Research Institute (NGRI), Hyderabad, Atomic Minerals Division (AMD), New Delhi, Central Electricity Authority (CEA) and others.

Classification of Thermal Springs

Classification of Thermal Springs

About 300 thermal springs are known to occur in India. These thermal springs occur along the length and breadth of the country extending from Jammu and Kashmir in the north to Tamil Nadu (Kanya Kumari) in the south over a distance of about 5000 km, and from Gujarat in the west to Arunachal Pradesh in the east over a distance of 4000 km. The springs have been classified on the basis of their occurrence in specific geotectonic set ups and have been grouped under different geothermal provinces. However, on the basis of enthalpy characteristics, the geothermal systems in India can be classified into medium enthalpy (100-200°C) and low enthalpy (less than 100°C) geothermal systems. Medium enthalpy geothermal systems are known to be associated with the following:

- Younger intrusive granites as in the Himalayas, viz. Puga-Chhumathang, Parbati, Beas and Satluj geothermal fields.
- Major tectonic features/lineaments such as the west coast areas of Maharashtra; along the Son-Narmada-Tapi lineament zone at Salbardi, Tapi - Satpura areas in Maharashtra, Tattapani in Madhya Pradesh and Rajgir-Monghyr in Bihar and Eastern Ghats of Orissa.
- Rift and grabens of Gondwana basins viz. Damodar, Godavari and Mahanadi.
- Quaternary and Tertiary sediments in a graben, viz. Cambay basin off West Coast.

Low enthalpy geothermal systems are associated with the following:

- Tertiary tectonism and neotectonic activity - north Indian geothermal field viz. Sohna and Rajasthan.
- Shield area with localised abnormal heat flow which is normally very low - south Indian geothermal province.

The medium enthalpy waters could be utilised for either primary cycle power production (Puga geothermal system) or binary cycle power production using different types of freons (Tattapani geothermal system, Madhya Pradesh). The thermal water flowing at other areas, in Maharashtra, Himachal Pradesh, Haryana and Uttar Pradesh, although they fall in medium enthalpy geothermal systems, can be utilised for non-electrical applications only. The thermal water flowing from low enthalpy geothermal systems does not have much scope for harnessing of geothermal energy at present. Thermal water discharging from most of the geothermal systems in India, at present, have better scope for non-electric application.

Small scale experimental utilisation studies have been carried out at Puga, Chhumathang geothermal fields and at Manikaran in Parbati valley geothermal field. At present, the Puga geothermal field is the only field capable of producing either primary cycle electrical power or binary cycle power, that too on a very small scale. The thermal fluids have been utilised for heating of spaces, processing of borax and sulphur and extraction of salts. Its use in the extraction of the rare metal cesium is under experimentation. Poultry farming and green house cultivation are the other industrial applications for which geothermal energy has been used. Thermal water energy has been successfully used for hatching poultry and for the growth of mushrooms in an enclosed hut, 500 sq m in area, by the Regional Research Laboratory, Jammu.
The need to have a sustainable supply necessitates the exploitation of available energy sources, and among these, renewable resources are at the forefront.

It is now an established fact that RE (renewable energy) can be an integral part of sustainable development because of its inexhaustible nature and environment-friendly features. RE can play an important role in resolving the energy crisis in urban areas to a great extent. Today RE is an established sector with a variety of systems and devices available for meeting the energy demand of urban inhabitants, but there is a need to create mass awareness about their adoption.

Akshay Urja is an attempt to fulfil this need through its dissemination of 20,000 copies in India and abroad. The magazine publishes news, articles, research papers, case studies, success stories, and write-ups on RE. Readers are invited to send material with original photographs and statistical data. The photographs should be provided in high resolution files on a CD or through email. Akshay Urja will pay a suitable honorarium to the authors for each published article of 1500 words and above. The publication material in two copies, along with a soft copy on CD/DVD/e-mail may be sent to

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The benefits of using geothermal energy as an alternative resource are immense. Renewable, low running cost, capability to provide base load power, and small environmental footprint make this resource a preferred choice among other energy resources. However, considerable research and development is needed to take advantage of this buried wealth. The future use of geothermal energy would depend not only on overcoming technical barriers related to its utilisation and the economic viability compared to other energy resources but also on favourable policy initiatives from the government.

With rapidly increasing energy demands in growing economies such as India, it is important to include
sustainable energy resources in its fossil-fuel-dominated primary energy mix. Geothermal energy is one such resource derived from the Earth's internal heat, which has been catering successfully to both industrial as well as domestic energy requirements in many parts of the world over the past few decades. Being abundant, environmentally benign and renewable, it is a preferred choice for an alternative energy resource. Besides conversion to electric power, the direct uses of geothermal heat have the potential to replace substantial quantities of fossil fuels.

The worldwide utilisation of geothermal energy has increased rapidly during the last three decades mainly from variable capacity additions by Philippines, United States, Italy, New Zealand, Iceland, Costa Rica, El Salvador, Guatemala and Russia (Table 1). Today, besides being used in at least 24 countries to generate electricity totalling about 10,700 MW installed capacity (R. Bertani, Proceedings, World Geothermal Congress, Indonesia, 2010), geothermal energy is being used in more than 58 countries.

Table 1. Countries Generating Geothermal Power in 2010

<table>
<thead>
<tr>
<th>Countries</th>
<th>Installed Capacity (MW)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>3,086</td>
<td>1</td>
</tr>
<tr>
<td>Philippines</td>
<td>1,904</td>
<td>2</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1,197</td>
<td>3</td>
</tr>
<tr>
<td>Mexico</td>
<td>958</td>
<td>4</td>
</tr>
<tr>
<td>Italy</td>
<td>843</td>
<td>5</td>
</tr>
<tr>
<td>New Zealand</td>
<td>628</td>
<td>6</td>
</tr>
<tr>
<td>Iceland</td>
<td>575</td>
<td>7</td>
</tr>
<tr>
<td>Japan</td>
<td>536</td>
<td>8</td>
</tr>
<tr>
<td>El Salvador</td>
<td>204</td>
<td>9</td>
</tr>
<tr>
<td>Kenya</td>
<td>167</td>
<td>10</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>166</td>
<td>11</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>88</td>
<td>12</td>
</tr>
<tr>
<td>Russia</td>
<td>82</td>
<td>13</td>
</tr>
<tr>
<td>Turkey</td>
<td>82</td>
<td>14</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>56</td>
<td>15</td>
</tr>
<tr>
<td>Guatemala</td>
<td>52</td>
<td>16</td>
</tr>
<tr>
<td>Portugal</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>China</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>France</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>7.3</td>
<td>20</td>
</tr>
<tr>
<td>Germany</td>
<td>6.6</td>
<td>21</td>
</tr>
<tr>
<td>Austria</td>
<td>1.4</td>
<td>22</td>
</tr>
<tr>
<td>Australia</td>
<td>1.1</td>
<td>23</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.3</td>
<td>24</td>
</tr>
</tbody>
</table>

Source: www.geo-energy.org

Table 2. Major hot spring groups in India, their tectonic settings and temperatures of surface waters

<table>
<thead>
<tr>
<th>Major hot spring groups</th>
<th>Tectonic setting</th>
<th>Temperature range of surface discharge, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indus valley (Puga, Chhumathang)</td>
<td>Higher Himalaya (active tectonic zone)</td>
<td>75-100</td>
</tr>
<tr>
<td>Parbati valley (Manikaran), Beas valley, Satluj valley, Tapoban group in Uttarakhand, etc</td>
<td>Central to Lesser Himalaya</td>
<td>50-90</td>
</tr>
<tr>
<td>Tattapani group, Chhattisgarh</td>
<td>Central Indian shield (stable craton)</td>
<td>75-100</td>
</tr>
<tr>
<td>Son-Narmada-Tapti lineament zone (SONATA)</td>
<td>Central Indian shield (stable craton)</td>
<td>30-65</td>
</tr>
<tr>
<td>Bakhreswar-Tanfloi, Monghyr, Rajsir, Surajkund, etc</td>
<td>Eastern India (stable craton)</td>
<td>45-71</td>
</tr>
<tr>
<td>West Coast group, Maharashtra</td>
<td>Deccan Traps (stable craton)</td>
<td>35-70</td>
</tr>
</tbody>
</table>

@ In addition to the major hot spring groups listed above, several low-to-moderate temperature springs occur in Haryana, Gujarat, Andhra Pradesh, Karnataka, Odisha, Assam, Meghalaya and Arunachal Pradesh
India is yet to produce electric power from geothermal energy, except for a nominal, 5kW, binary plant at Manikaran that was operational for a very short time only.

Among the most notable achievements during the past five decades has been the assessment of geothermal fields by the Government of India in 1966 and publication of a comprehensive report in 1968 recommending preliminary

**Geothermal Exploration in India**

In most precambrian terrains including India, moderate-to-low temperature hot water spring systems represent the potential geothermal energy resources. This scenario is in contrast to steam and/or steam and hot water based geothermal fields under production in other parts of the world, which are located predominantly in quaternary volcanic / magmatic settings (Fig 1). The major groups of hot springs in India occur in the Indus valley (Fig 2, Puga - Chhumathang), Parbati valley (Manikaran) and Tapoban areas in the Himalaya; along the west coast of Maharashtra in western India; the Son-Narmada-Tapti lineament zone in central India; Tattapani (Fig 3), Rajgir-Monghyr, Surajkund and Bakreshwar in eastern India. The distribution of major groups of hot springs in India is shown in Fig 4 and temperature ranges of geothermal waters are listed in Table 2. Most hot springs occur in the foothills or river valleys and the waters are predominantly meteoric in origin.

No evidence of quaternary magmatism is reported, except in the case of Puga-Chhumathang areas where conclusive evidence is lacking. Therefore, the preferred model for most hot springs in India is that of rainwater/snowmelt infiltrating into the subsurface, the downgoing waters picking up heat from the Earth’s normal heat flow and returning to the surface through fault / fracture systems. Geothermal springs have been used mainly for balneological purposes and religious tourism. However, India is yet to produce electric power from geothermal energy, except for a nominal, 5kW, binary plant at Manikaran that was operational for a very short time only.

India is yet to produce electric power from geothermal energy, except for a nominal, 5kW, binary plant at Manikaran that was operational for a very short time only.
prospecting of the Puga and Manikaran geothermal fields in the Himalaya (Report of the Hot Springs Committee, Govt. of India, 1968). A major, systematic, multi-disciplinary, multi-institutional programme (including drilling up to 385 m) covering the Puga-Chumathang geothermal fields in Ladakh was mounted during 1972-74 under the stewardship of V.S. Krishnaswamy of the Geological Survey of India (GSI) and complemented by scientists from the Council for Scientific and Industrial Research-National Geophysical Research Institute (CSIR-NGRI), Central Electricity Authority and others. The shallow subsurface features were delineated in considerable detail that resulted in building a proposal to set up a pilot-scale, 1 MWe binary-cycle power plant at Puga. The proposal is yet to be implemented. Attempts to revisit the geothermal exploration in the area include a number of geochemical studies (see for example, Geothermal Energy in India, U.L. Pitale and R.N. Padhi (Eds.), Geological Survey of India, Special Publication 45) and recent magnetotelluric studies (Abdul Azeez and Harinarayana, Curr. Sci., v. 93, p. 323-329, 2007). An expert group set up in 2008 by the Ministry of New and Renewable Energy, Government of India made strong recommendations to install pilot-scale plants by drilling exploration cum demonstration wells in the area (Report of Expert Group on Power Generation from Geothermal Energy at Puga, Jammu and Kashmir, India : Ministry of New and Renewable Energy, Govt. of India, 2008). This would be useful not only for monitoring the rates of hot water discharge and temperatures over a period of time but also studying the reservoir characteristics. Another major initiative, directed towards the hot springs of the West Coast belt and the Son-Narmada-Tapti belt that was taken up by the GSI with assistance from the United Nations Development Programme (UNDP) during 1976-77 and later extended for a few years, included deep drilling up to depth of 500 m (Records of the Geological Survey of India, v. 118, Pt. 6, 1987). The Tattapani hot springs in Chhattisgarh were identified for setting up of a 300 kWe binary-cycle power plant. Although substantial geologic information on the Puga and Tattapani geothermal fields has been acquired, the lack of deep exploration, at least to depths of a few kilometres, hinders reservoir characterisation and evaluation of realistic geothermal energy potential. Much less information is available about the other geothermal fields in the country.

In recent years, the Ministry of New and Renewable Energy (MNRE), Government of India has shown renewed interest in geothermal exploration in different geothermal areas of the country besides creating the framework for a national policy on exploitation of geothermal energy resources. Results emerging from these programmes will provide useful information and guide further exploration efforts in the country. Direct uses of warm-to-hot geothermal waters for greenhouse heating in cold climates, development of tourist spas, agricultural product processing, and extraction of rare materials like cesium also provide significant economic and environmental benefits from replacement of fossil-fuel use in environmentally sensitive areas.

Additionally, the CSIR-NGRI has a dedicated heat flow studies programme since its inception in 1962, which has...
generated valuable data sets on the geothermal gradient and regional heat flow from temperature measurements in more than 500 boreholes covering a number of geologic and tectonic provinces in the country (S. Roy, Heat flow studies in India during the past five decades, Memoir 68, Geological Society of India, pp. 89-122, 2008). Detailed characterisation of thermophysical properties of major rock formations are carried out routinely to facilitate modelling of the temperature distribution in the crust in different parts of the country. Areas with anomalous high temperatures in the top 1-4 km of the crust, appropriate for enhanced geothermal systems (EGS) and hot sedimentary aquifers (HSA) could be delineated from such datasets.

**Perspectives for Development of Geothermal Energy**

**Re-assessment of Energy Potential of Conventional Geothermal Resources:** Temperature of hot spring waters at the surface is not the sole indicator of energy potential. The major question to be addressed is the sustainability of the resource, i.e., for how many years the production of hot waters at a certain minimum temperature and flow rate can be sustained. Answers to these questions require apriori information about characteristics of the subsurface reservoir and the nature of the heat source.

In view of the growing energy demands and the emphasis on renewable energy in India, a re-assessment of the geothermal energy potential of the Puga Valley hot springs in Ladakh and Tattapani hot springs in Chhattisgarh should be carried out. Critical gaps in information need to be covered through acquisition of new data, combined interpretation of geothermal datasets and existing geological, hydrological, geochemical and geophysical datasets to throw light on the nature of the heat source of the hot springs and their sustainability for power production, undertaking drilling and setting up of pilot-scale binary-cycle power plants. Scientific and statistical datasets including estimates of benefits from using geothermal energy should be compiled. These datasets could influence national policy decisions for providing tax incentives to investors and helping them tide over the increased upfront production costs of geothermal power when compared to conventional fuels.

**Development of appropriate power generation technologies:** Geothermal resources vary widely from one location to another, depending on the temperature and depth of the resource, the rock chemistry, and the abundance of groundwater. The type of geothermal resource determines the method of its utilisation. Variants of binary cycles appropriate to optimum utilisation of geothermal heat from moderate-to-low enthalpy springs in non volcanic settings such as those in India, need to be developed.

Efficient deep drilling technology is another important area requiring research and development in the country as drilling and distribution account for the largest costs, development of improved technologies to help contractors in difficult drilling environments help make deeper drilling economically viable, thereby providing access to higher temperature resources for power generation. Technological solutions to problems of corrosion and calcite deposition in pipelines, usually associated with geothermal systems, must be sought. Appropriate re-injection strategies, deep drilling and well stimulation are the key drivers for the producing fields to remain potential and economical in the long run.

**Direct heat uses:** The heat extracted from warm-to-hot waters emerging from other hot spring systems in the country can be gainfully employed for a number of direct uses such as development of tourist spas for bathing, swimming and balneology, greenhouse cultivation in cold climates, extraction of borax and rare materials such as cesium, and agricultural product processing. The significant economic and environmental benefits of using moderate-to-low enthalpy geothermal waters to replace even small...
The viability of geothermal heat pumps for heating inside buildings should be explored in the states of Jammu and Kashmir, Himachal Pradesh and parts of Uttarakhand.

quantities of conventional fuels for direct uses cannot be ignored today in view of the steep increase in costs of fossil fuels and associated greenhouse gas emissions.

**Geothermal Heat Pumps:** A geothermal (or ground-source) heat pump makes use of the relatively stable temperature at a depth of a few meters in the ground. During winter, the subsurface temperature is warmer than the room temperature inside a house, whereas during summer the subsurface temperature may be cooler. Geothermal heat pumps, therefore, can be extensively used for space heating in winter and cooling in summer, replacing fossil-fuel driven electrical heating and cooling systems. Heat pump systems use groundwater aquifers and soil temperatures in the range 5°C to 30°C. Heat pumps utilising very low-to-moderate temperature fluids have extended geothermal developments to countries that have not been using geothermal energy extensively such as France, Switzerland, Sweden, and areas of the mid-western and eastern United States of America. An assessment of the technology for suitability to Indian conditions is yet to be carried out.

The viability of geothermal heat pumps for heating inside buildings should be explored in the states of Jammu and Kashmir, Himachal Pradesh and parts of Uttarakhand which experience severe winter conditions for long periods. Space cooling requirements in most parts of India have grown several fold in the recent years with the growth in economy. There is enormous scope for developing the capabilities in geothermal cooling of buildings by modifying existing technologies to suit Indian conditions. A proper assessment of the technology for application to different climatic environments existing in the region, and its exploitation by integrating it with building designs should be encouraged.

**Exploration for Enhanced Geothermal Systems:** A non-conventional geothermal resource traditionally referred to as ‘hot dry rock’ and more recently as ‘enhanced geothermal systems (EGS)’, has not yet been explored in India. The primary requirement for such a resource is the occurrence of high temperatures (typically upwards of 150°C) at economically viable depths (typically the top 1-4 km of the Earth’s crust). Areas of anomalous high heat flow, high-heat-producing granites and other silicic igneous intrusive bodies having a depth extent of a few kilometres, could be possible targets for future exploration efforts in the country (Roy, 2008). These considerations reinforce the need for carrying out systematic heat flow as well as radiogenic heat production investigations on a country-wide scale.

**Summary**

Moderate-to-low enthalpy hot spring systems primarily represent the known geothermal energy resources in India. These resources are distributed in diverse physiographic and tectonic settings, viz., the Himalayan belt and the Precambrian shield. Detailed geological and geochemical exploration followed by limited geophysical exploration and shallow drilling investigations up to a few hundred metres only, have resulted in first-order geothermal models for the major hot spring zones in the country. However, the development of the geothermal resources has remained at a very low level mainly due to inadequate characterisation of the deeper thermal regime, leading to low confidence in proposed reservoir models and sustainability of the heat source. There is therefore an urgent need to carry out a reassessment of the geothermal energy potential of hot springs by employing new geophysical probing tools and computational techniques available today, both for electric power generation as well as for direct uses. Efficient exploitation technologies appropriate to non-volcanic areas need to be developed. Systematic heat flow and heat production investigations need to be carried out for the identification of areas where high temperatures in the top few kilometers below the ground surface indicate potential for ‘hot sedimentary aquifers’ as well as ‘enhanced geothermal systems’. The vast potential for geothermal heat pumps is yet to be tapped. The existing heat pump technology must be modified and made accessible to individuals and small communities to serve as a low-cost alternative to use of fossil fuels for their space heating and cooling needs. Development of ocean thermal energy conversion technologies must be promoted and the benefits from low temperature thermal desalination of seawater made available to widespread island communities. Enabling policy guidelines from the MNRE will facilitate rapid progress in exploration and development of geothermal energy resources.

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Bioelectric effects of ‘electric’ fish like the Nile Catfish and Electric Eel are well known since ancient times. Bioelectricity is the process that is produced by or occurs in a living organism which can be transformed chemically to produce bioenergy which is both sustainable and renewable.

Harnessing bioelectricity through microbial fuel cell from wastewater

Dr S Venkata Mohan

The microbial fuel cell (MFC) has garnered significant interest in both basic and applied research due to its sustainable and renewable nature in the contemporary energy scenario and is all set to be the trendsetter in the arena of answers to the complex environmental pollution problems and the energy crisis, with a unified approach. The MFC is essentially a hybrid bio-electrochemical system which directly transforms chemical energy stored in the biodegradable substrate to electrical energy via microbial catalysed redox reactions involving microorganisms as biocatalysts under ambient temperature/pressure. The biocatalytic activity of the microorganisms present in the anode chamber generates the reducing equivalents [protons (H+) and electrons (e-)] through a series of bio-electrochemical redox reactions during substrate degradation in absence of oxygen. These protons and electrons are the source of electricity generation in MFC. The electrochemically active nature of a microorganism supports the effective pumping of redox powers. The MFC has multiple applications based
on the utilisation of reducing equivalents with different nomenclature. Reducing equivalents facilitate hydrogen production in microbial electrolysis cell (MEC), by-product recovery either from anode or cathode chambers in bio-electrochemical system (BES) and enhanced pollutant removal using bio-electrochemical treatment system (BET).

**Principle behind MFC Operation**

The MFC functions on the basis of anodic oxidation and cathodic reduction reactions. The anode chamber is a biofactory which facilitates the generation of protons and electrons and plays a crucial role between physical and biological components. Protons reach the cathode through the proton exchange membrane (PEM) resulting in a potential difference against which the electrons flow through the circuit (current) towards counter electrode (cathode) and get reduced in presence of oxygen forming water.

\[
\begin{align*}
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} &= 6\text{CO}_2 + 24\text{H}^+ + 24\text{e}^- \quad \text{(Anode)} \\
4\text{e}^- + 4\text{H}^+ + \text{O}_2 &= 2\text{H}_2\text{O} \quad \text{(Cathode)} \\
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2 &= 6\text{CO}_2 + 12\text{H}_2\text{O} \quad \text{(Overall)}
\end{align*}
\]

Electrons in the cascade of respiratory chain, transfers between the proteins through redox reactions based on the oxidation reduction potentials of the proteins. The proton flowing across inner and outer membranes based on the redox potentials of cascade, generates a proton motive force and it mobilises the electrons towards inter membranous space. Since electrons must transfer from a more negative potential to a less negative potential, the extra cellular electron transfer rate is influenced by the potential difference between the final electron carrier and the anode. Activity of anodic bacteria is essential to liberate electrons from the oxidation of organic matter and to transfer them to the electron acceptor. Electrons will be driven to the anode by a potential difference between the terminal intracellular electron acceptor and the anode either by direct electron transfer (DET) or mediated electron transfer (MET). Membrane-bound proteins or conductive biofilm (nanowires) facilitate DET while MET occurs through soluble shuttling compounds. Microorganisms use more than one electron transfer mechanism to transfer electrons to the anode. The DET is considered to be a comparatively, more effective mechanism than the MET where the electron losses can be minimised prior to reaching the anode surface. Microorganisms are able to form a biofilm on anodes, which plays a crucial role in DET. The nature and group of consortia in the biofilm specifically regulates the electron discharge onto anode. Surface positive charge of anode gets increased due to the developed in situ bio-potential which enables the adhesion of negatively charged bacteria. Interaction among the microorganisms also facilitates efficient electron transfer.

The MFC systems are designed with dual and single chamber configurations. The double chamber configuration has separate anode and cathode compartment connected through a PEM (Fig 1 and 2). The substrate gets oxidised in the anode chamber while reduction occurs in the cathode chamber. Catholytes such as potassium ferricyanide, potassium permanganate, aerated catholytes, etc. were used with variable degree of efficiency. The single chamber MFC configuration consists of the anode chamber only, while cathode is placed in such a way that it is exposed to air (open-air cathode) (Fig 3). Few other configurations viz., flat plate, tubular, cubical, stack, etc. have also been used for MFC operation. The solid phase microbial fuel cell (SMFC) was designed by Council for Scientific and Industrial Research-Indian Institute of Chemical Technology (CSIR-IICT) to evaluate the potential canteen based food waste as substrate for bioelectricity generation. A photo-bioelectrocatalytic/photo-biological fuel cell (PhFC) was designed by CSIR-IICT to evaluate bioelectricity generation using photosynthetic consortia as the biocatalyst in the mixotrophic mode. Syntrophic association of photosynthetic bacteria and algae showed feasibility of power generation under anoxygenic
microenvironment by the PhFC. Benthic/sediment type fuel cell application for bioelectricity generation was evaluated in different types of water bodies. Nature, flow conditions and characteristics of water bodies influence the power generation apart from electrode assemblies, surface area of anode and anodic material. The CSIR-IICT evaluated designed miniaturized floating macrophyte based ecosystem with Eichornia as the major biota for bioelectricity generation from wastewater treatment employing three fuel cell assemblies (similar to benthic fuel cell). Based on the observations made from various lab scale optimisation studies, the CSIR-IICT developed a semi-pilot scale hybrid bio-electrochemical system with 100 litre capacity using multiple electrode assemblies connected in series (36 chambers) (Fig 4). The semi-pilot scale MFC without membrane was evaluated for one year using domestic sewage operated under anoxic conditions.

**Wastewater vs Bioelectricity**

The concept of the MFC is well established in the direction of utilising wastewater as an anodic fuel making it a sustainable technology for energy generation as well as waste management. Reducing the cost of wastewater treatment and finding ways to produce useful byproducts has been gaining importance in view of environmental sustainability. The organic matter present in wastewater serves as primary substrate for the fermentation process facilitating treatment of wastewater with simultaneous generation of bioelectricity. Theoretically, one kg of chemical oxygen demand (COD) removed can produce 170 W of power. According to an estimate, about 300 million tons of wastewater is generated annually in India by dairy industries which can generate bioelectricity using the MFC method (calculated assuming 40 per cent energy conversion efficiency; 14.7 KJ/g-COD) accounting for a revenue of Rs 12 billion per annum (at a rate of Rs 4 per kWh) along with its treatment. Domestic sewage generated in urban and rural areas of India was estimated to be around 1,42,405 million litre/day (MLD) which could generate about 300 MW/h power accounting for a cost of about Rs 108 billion per annum apart from treatment. This gives a clear estimate about the inherent power present in wastewater that can be harnessed for bioenergy. Wastewater from food waste, electroplating, starch processing, breweries, paper industry, palm oil mill, chocolate industry, domestic sewage, cellulosic waste, vegetable waste, composite chemical wastewater, pharmaceutical wastewater, swine waste, etc. were evaluated at a laboratory scale to understand their potential as anodic fuel and the possibility of power generation from various types of wastewater was evaluated at CSIR-IICT (Table 1).

**MFC as treatment unit**

The MFC can also be termed as a bio-electrochemical treatment (BET) system. The principle of BET relies on the fact that electrochemically active microorganisms can transfer

**Table 1. Bioelectricity production from various wastewaters as substrate evaluated in different types of MFC configurations**

<table>
<thead>
<tr>
<th>Waste/Wastewater</th>
<th>Maximum Voltage (mV)</th>
<th>COD removal (per cent)</th>
<th>Volumetric Power (W/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Chemical</td>
<td>731 (dual)</td>
<td>61.1 (dual)</td>
<td>4.95 (dual)</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>339 (single) 625 (hybrid)</td>
<td>76.0 (single) 92.1 (hybrid)</td>
<td>8.40 (single) 0.99 (hybrid)</td>
</tr>
<tr>
<td>Dairy</td>
<td>308 (single)</td>
<td>95.5 (single)</td>
<td>3.56 (single)</td>
</tr>
<tr>
<td>Distillery</td>
<td>351 (single)</td>
<td>72.8 (single)</td>
<td>4.96 (single)</td>
</tr>
<tr>
<td>Canteen Waste</td>
<td>332 (single)</td>
<td>88.7 (single)</td>
<td>2.17 (single)</td>
</tr>
<tr>
<td>Domestic Sewage</td>
<td>449 (single)</td>
<td>66.7 (single)</td>
<td>2.25 (single)</td>
</tr>
<tr>
<td>Designed Synthetic</td>
<td>586 (dual) 308 (single)</td>
<td>72.2 (dual) 43.7 (single)</td>
<td>3.95 (dual) 1.86 (single)</td>
</tr>
<tr>
<td>Vegetable market waste</td>
<td>308 (single)</td>
<td>80.0 (single)</td>
<td>4.60 (single)</td>
</tr>
<tr>
<td>Citrus Peelings</td>
<td>321 (single)</td>
<td>71.0 (single)</td>
<td>1.76 (single)</td>
</tr>
</tbody>
</table>

*Power yield varied between 5-12 W/kg CODR
electrons from a reduced electron donor to an electrode and finally to an oxidised electron acceptor generating power. During a BET operation, there exists a possibility to integrate diverse components viz., biological, physical and chemical in the anodic chamber and provides an opportunity to trigger multiple reactions viz., bio-chemical, physical, physico-chemical, electrochemical, oxidation, etc., as a result of substrate metabolic activity and subsequent secondary reactions. The anode chamber of the BET resembles the conventional anaerobic bioreactor and mimics the function of a conventional electrochemical cell used for wastewater treatment where the redox reactions help for the degradation of organic matter and toxic/xenobiotic pollutants. Anodic oxidation and cathodic reduction reactions will have a positive influence on the pollutant removal in the BET system. The in situ bio-potential generated during the process helps in the enhanced degradation of different pollutants in both the anode and cathode chambers. Direct anodic oxidation (DAO) and indirect anodic oxidation (IAO) facilitate the effective removal of pollutants. The DAO facilitates the degradation of pollutants absorbed on the anode surface by anodic electron transfer reactions. The oxidants formed electrochemically on the anode surface in turn oxidise the organic matter by IAO. The DAO of the substrate facilitates the formation of primary oxidants which could further react on the anode, yielding secondary oxidants such as chlorine dioxide and ozone, which might have a positive effect on the colour removal efficiency through the oxidation process. This process helps to oxidise the organic matter by the liberated oxidation species which might enhance the substrate removal. Reactions between water and radicals near the anode could yield molecular oxygen, free chlorine, hydrogen peroxide, hypochloric acid, etc. which also helps in colour/organic oxidation. Pollutants in the anodic chamber also act as mediators for the electron transfer to anode which can increase the power generation efficiency with simultaneous reduction of pollutants. Various pollutants such as dyes, organic pollutants, solvents, inorganic salts, complex wastewater, coloured substances, synthetic estrogens, PAHs, etc. are reported to be treated in these systems. Application of biocathode also helps in enhancing wastewater treatment efficiency especially in the removal of specific pollutants. Biocathodes reportedly reduced pollutants such as nitrates or sulfates or chloroorganics in the cathode compartment.

**Factors influencing bioelectricity generation**

Electrical energy can be obtained from fuel cell operation only when a reasonable current is drawn, but the actual cell potential is decreased from its equilibrium potential because of irreversible losses present in the fuel cell. Electron transfer from the biocatalyst to the anode and then to the cathode is generally hampered by different losses which lower the conversion efficiency. There exists a close similarity between bio-electrochemical and biochemical reactions wherein both encounter an activation barrier that must be overcome by the reacting species or biocatalyst. The power generation capacity of the MFC depends on the catabolic activity of the anodic biocatalyst and its electron transfer efficacy to the anode. However, the transfer of electrons between the biocatalyst and the anode is low because of the sluggish kinetics which subsequently results in a low power yield. The electron transfer resistances in the MFC arise due to factors such as the reactor configuration, materials used, nature of anolyte and metabolic activities of the biocatalyst, which tend to decrease the MFC performance pertaining to power generation as well as substrate degradation. The power output of the MFC can be improved by enhancing the electron transfer efficiency between the biocatalyst and the anode. Most of the earlier studies with the MFC were reported with pure culture as biocatalyst with simple defined substrates. However, usage of mixed culture instead of single strains is always a better option in the MFC operation because of ease in maintenance and their survivability even in wastewater. Selective enrichment of the mixed culture with an electrochemically active bacterial population will have more benefits. Poising mild potentials during reactor start up, growth under restricted electron mediating conditions, bio-augmentation of electrochemically active strains, etc., are few strategies developed for the selective enrichment of biocatalysts. The nature of the anode will also have significant influence on the substrate conversion efficiency and the synergistic interaction between anode and biocatalyst is crucial for efficient extracellular electron transfer. High electrical conductivity (low electrical resistance), inert nature (non-oxidation/non self-destructive nature), sustainability of properties with time, etc. are some
of the important properties of the anode which can influence the performance of the MFC. More often, graphite is used as a bioanode material for fuel cell applications in both catalysed and non-catalysed forms. Few other materials viz., platinum, stainless steel, nickel, etc., were also used as anode apart from carbon based materials. Extracellular electron transfer will be high under acidophilic pH compared to neutral and basic pH due to the higher activity of intracellular electron carriers which helps in translocation of electrons from bacteria to the extracellular environment. On the contrary, wastewater treatment was reported to be higher under neutral pH. Ion exchange membrane between anode and cathode for the development of a gradient is also an important factor that influences the MFC performance. Usually, the anode chamber of MFC will be operational in an anaerobic microenvironment. However, very few studies have reported that, aerobic microenvironment under low DO - dissolved oxygen (anoxic) conditions and high substrate concentration will have a potential to generate power. Cathodic reduction of reducing equivalents is crucial along with the anodic oxidation for power output in the MFC system. Reduction reaction at the cathode indirectly influences the substrate oxidation in the anode as well as it can help to overcome the electron losses. Microorganisms can also be used as a catalyst in the cathode chamber for improved cathodic reduction reaction where biocatalysts retrieve electrons directly from the cathode which are then transferred to a final electron acceptor such as oxygen, nitrogen, sulfur, etc. The electron transfer in the MFC can also be increased by using different types of artificial and natural mediators. Genetic modification of specific genes in the biocatalyst related to the proteins that function for the exocellular electron transfer, was also reported by a few researchers. The operation of the MFC under the optimised conditions with selectively enriched mixed culture as catalyst and wastewater as substrate will have a commercial viability in the near future.

Fig 3. Photograph showing single chamber MFC with open-air cathode (L). Fig 4. Semi-pilot scale MFC (without membrane) with 100 litre capacity was designed with 36 chambers and evaluated for more than one year using domestic sewage (R).

Future Scope
The MFC is poised to change the visage of the energy scenario and wastewater treatment processes in the near future. However this requires extensive research with respect to appropriate design of fuel cell, effective reactor configuration, low cost components of fuel cell, reduction in electron loss, etc. Interaction between the anode and the biocatalyst needs to be understood and optimised to fully exploit the capacities of these systems. At present, apart from power generation, the MFC application has been extended towards waste remediation, specific pollutants removal and recovery of value added products. Bio-electrochemical treatment is gaining prominence which will facilitate enhanced treatment efficiency with simultaneous energy generation. Based on the oxidation reduction reactions occurring in the MFC, various complex pollutants can be removed by increasing the power generation potential, especially in the cathode chamber. The other face of the MFC is recovering value added products from the carbon source present in waste through bio-electrochemical process and the conversion of wastewater components or CO₂ into valuable products under mild applied potential. This is based on the reduction mechanism at cathode and by reducing the activation energy required for the conversion of waste carbon to valuable product through applied potential associated with the in situ biopotential. Biocatalysed electrolysis is a novel H₂ production process with a potential of converting dissolved organic substances in wastewater, in the absence of electron acceptor under small external voltage (>0.2 V in practice). Other value added products viz., ethanol, butanol, etc., can also be recovered at cathode of bioelectrochemical systems but these studies are at an early stage and needs optimisation of process parameters. The applications of the MFC are at present in the developing stage, but it will make every effort to meet the energy needs of society by utilising waste carbon resources in the near future.

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BET relies on electrochemically active microorganisms that can transfer electrons from a reduced electron donor to an oxidised electron acceptor generating power.
Hydrogen as an everyday fuel is indeed a revolution in science. Useful as a compact energy source in fuel cells and batteries, it is renewable and causes no pollution. Though the discovery of its use is considered a breakthrough, its cost effectiveness is yet to be ascertained.

Prof. Dileep Kumar Krishna Nayak and Prof. Usha Raghavan

Hydrogen - A Promising Renewable Fuel

R
evolutions in science and industrialisation may have enhanced the use of machines. Indeed these machines help improve the quality of human life. However, it is well known that these require energy and consequently, the energy requirement of the world is increasing at an alarming rate. According to the recent World Energy Outlook 2008, we derive around 80 per cent of our energy from fossil fuels like crude oil (36 per cent) natural gas (21 per cent) and coal (23 per cent) (Fig 1). It is also well known that these fossil fuels are exhaustible and will get depleted very soon. Hydrocarbon resources are in the mid depletion stage and are likely to last for about five decades whereas coal reserves may be adequate for only a couple of centuries.

Most developing nations have a huge difference between the demand and supply of electrical energy. To keep pace with advancement and progress it has become necessary to strengthen power generation capabilities thus taking a toll on the available fossil resources. The growing population
The use of hydrogen largely reduces pollution. When hydrogen is combined with oxygen in a fuel cell, energy in the form of electricity is produced.

Clearly, hydrogen is poised to be one of the potential energy sources of the future. It has three basic benefits:

- The use of hydrogen largely reduces pollution. When hydrogen is combined with oxygen in a fuel cell, energy in the form of electricity is produced.
- Hydrogen can be produced from numerous sources such as methane, gasoline, biomass, coal or water.
- If energy is produced from water, it becomes a sustainable production system.

Thus, the issues related to energy, pollution, environment and sustainability can be tackled effectively using hydrogen energy. Hydrogen is also the lightest of all elements and is available in abundance. If a matured technology is developed, hydrogen can become the cleanest, most efficient and cost effective fuel. The main advantage of hydrogen energy is that it is produced from water, used as an energy carrier and its byproduct is also water. Extensive research is taking place for the generation of pure hydrogen, its handling, storage, efficiency and safety aspects.

Properties of Hydrogen

Hydrogen is a light, odourless and colourless gas with a density that is 14 times lesser than that of air at standard temperature and pressure and liquefies at temperatures below -253° C. Its energy per unit mass content is around 141.9 MJ/kg which is around thrice of that of gasoline. Hydrogen does not occur naturally as a gas on earth - it is always found in combination with other elements. It is present in large quantities in water as also in many organic compounds - in gasoline, natural gas, methane, etc.

Production of Hydrogen

Hydrogen is produced using various technologies; depending on the methods by which hydrogen is liberated, they are classified as steam reforming, electrolysis of water, gasification and partial oxidation.

- **Steam Reforming:** The method consists of reforming hydrocarbons into their compounds with steam, using endothermic reaction. Hydrocarbons, mixed with steam at a temperature of about 1100° C under pressure, using a catalyst such as nickel, react to release hydrogen.
- **Electrolysis of water:** Water breaks apart into hydrogen and oxygen when an electric current is passed through the electrolyte. The positively charged ions are attracted by the cathode where H₂ molecules are released. Oxygen is released at the anode. This method needs electric current which can be provided through renewable sources like solar, wind, etc.
- **Gasification:** It is one of the oldest methods in which biomass or coal when mixed with a limited amount of oxygen at around 900°C, produces a synthesis gas (syngas) which contains hydrogen. After cleaning, it can be reformed into hydrogen.
- **Partial Oxidation:** The thermal degeneration of hydrocarbons produces hydrogen. Raw materials such as natural gas, oil, gasoline are used for the conversion.

Storage of Hydrogen

Hydrogen storage is one of the critical issues for successful implementation, commercialisation and sustainability of mobile applications like hydrogen fuelled automobiles. Various technologies used for storage of hydrogen are:

- Compressed hydrogen is essentially the gaseous state of hydrogen gas which is kept under pressure. Pressure in the order of 5000 psi - 10000 psi is used for hydrogen vehicles. However, the size of the tank is large which makes the storage system heavy.

![Fig 1. World Primary Energy Consumption, 2008](source: World Energy Outlook)
Liquid hydrogen (Fig 2) or slush hydrogen requires cryogenic storage (20 K). Liquefaction imposes a large energy loss since energy is required to cool it down to that temperature. The tank must be well insulated and is the kind that can be used in space shuttles.

Hydrogen can be stored in solid porous materials. Gas-on-solid absorption is inherently safe providing high density storage and increased safety.

Carbon nanotubes can be a promising mechanism for hydrogen storage. One of the critical factors in the usefulness of carbon nanotubes, as a storage medium is the ratio of stored hydrogen to carbon. According to the US Department of Energy, a carbon material needs to store 6.5 per cent of its own weight in hydrogen to be considered as a fuel for automobiles.

**Storage of Liquid Hydrogen**

**Safety:** Certain safety issues that concern the use of hydrogen as a fuel are that it is odourless, colourless and tasteless making it undetectable by human senses. Hence, a leakage will be very difficult to detect. Hydrogen burns very quickly and has a tendency to combine with other elements. Hence, before hydrogen is made available as a popular transport fuel, it is essential to make sure that the fuel is safe for mass storage. Issues related to control of combustion, explosion and detonation of hydrogen air mixtures are yet to be addressed.

**Application:** Hydrogen is high in energy, yet an engine that burns pure hydrogen produces no pollution. Hydrogen fuel cells have been used to power the electrical system of space shuttles. It is a promising technology for use as a source of heat and electricity for buildings and as an electrical power source for electric vehicles. Hydrogen has the potential to be an important energy carrier that can be delivered in a usable form to consumers.

**Conclusion**

Renewable hydrogen as a transport fuel is an attractive option, which can help the world in environment protection. However, it is important to make this source safe and commercially viable. The innovations happening at research laboratories are likely to provide necessary results to make the hydrogen economy a reality.

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Growing environmental consciousness and the adverse effects of climate change, are propelling governments to support initiatives towards the development of eco-friendly mobility solutions including electric vehicles. Efforts have to be made to orient the use of electric vehicles to niche situations and markets where their limitations can be leveraged by design.

K. Munshi

Increasing environmental consciousness and in view of the harmful effects of climate change, the Government of India and those of various Indian states are supporting various initiatives for the development of technologies, and reduction of the carbon footprint emanating from India. Regulation has become one of the prime factors driving this change. Energy audits have been made mandatory in large consumer units, since March 2007. An energy labelling programme for appliances was launched in 2006 and comparative star-based labelling has also been introduced. With the recent signing of the agreement on Climate Change, in Copenhagen, India is committed to pursuing this policy aggressively. The Government of India’s programme on ‘Urban Renewal’ insists on energy efficiency, and incentives in the form of cheaper loans are being offered to urban transport authorities. The National Solar Mission is promoting the use of solar energy for power generation and other applications. Energy efficiency has become the top most agenda for Indian companies as well. Big automobile companies are developing electric vehicle technologies and/or buying smaller electric vehicle companies to prepare for the future. A good example is that of Mahindra and Mahindra (M&M) who purchased the Reva Electric Car
Company. Tata Motors has also initiated development of electric cars in various segments. They believe that the future belongs to smaller cars and have showcased their efforts at various motor shows around the world.

The Challenge
Although the first electricity driven car was driven in the 1880s, it lost the race to gasoline powered vehicles due to its deficiencies in range, weight and time of charging. Despite having made great strides in technology in the last 100 years, the electric vehicle still suffers from the same problems to date. What is however encouraging is that serious thought is being given to add value and make these vehicles viable ‘somehow’ and ‘somewhere’. The rising cost of crude oil is helping this movement and the advantage is that it is posing challenges to various technology disciplines, and those working in these areas are doing their best to find solutions and attract research investment. With such inputs, it is bound to yield positive results in due course.

Strategy
Presently, on a global scale, effort is to build cars which can replace the existing petrol / diesel driven cars. However, this makes these cars very expensive and therefore unacceptable. It will take quite some time before these vehicles (hybrid or pure electric or hydrogen based) can compete on price with existing vehicles. As an immediate strategy to make electrical vehicles acceptable and usable, efforts may be made to design and orient the use of specialised electric vehicles to niche situations and markets, where these vehicles can have an intrinsic edge over conventional vehicles. This needs to be understood well. If the limitations of the electric driven vehicles are leveraged by design, then special vehicles for special applications / special situations can become viable and commonplace, thereby relieving the pressure on oil, environment (pollution), health and carbon footprint, to an extent.

The limitation of range if understood, can let us identify areas where the range of a vehicle is not important. One such example is the airport. Airports have become an essential infrastructure of a city, however small. Airports are highly, traffic and surface vehicle intensive and therefore one of the most polluted areas of a cityscape. If analysed, the airport can lend itself very easily to vehicle electrification. All buses running in the airport for ferrying passengers to and from the aircraft to the terminals could be electric vehicles. One can argue that aero-bridges obviate the need for such traffic. However, aero bridges in the context of developing countries like India are available only in a few large city airports. The rest are still dependent on gas guzzling, carbon dioxide fuming buses for ferrying millions of passengers across airports, all over the country. Although it seems so obvious that we should have ‘electric ferry buses’ on the airports, but one is yet to see even one electric bus on any Indian airport. In fact to make
a small but very important beginning, not only buses, but all vehicles at the airports could be electricity driven, including aircraft tow tractor, baggage and food trolley towing tractors, maintenance runabouts, crew vehicles etc.

**Case Study**

A case study was developed through a project for the ‘design of electric aircraft tow tractor’ that tows the aircraft from runways to the tarmac or apron, and back. Presently it is a highly fuel guzzling and polluting vehicle, as it has to have weight (added through ballast) for traction to tow the heavy aircraft. Making it electric, can offer manifold advantages, which will be elucidated in the following case study. The disadvantage of an electric vehicle is that it is heavy, which is a positive aspect for an aircraft tow tractor. Cheaper, heavier and dependable lead acid batteries can be used as their high weight can create an advantage. The airport is a confined space; hence the range of the vehicle need not be large.

Intermittent usage (as it is not used all the time) of such vehicle can allow it to move to charging stations more often to get adequately charged. The structure of this vehicle need not be efficient and expensive (as in monocoque vehicles), but inefficient, heavy, rugged and less expensive. What we see here (Fig. 1) is that all the inherent disadvantages of an electric vehicle could be converted into advantages in this situation.

Similar advantages can be created in varying degrees in industrial campuses, gated communities, small urban clusters and similarly identified situations, with vehicles for different usages and where short ranges are fine.

**Education and Research**

A new masters and doctoral level programme was started from 2010 for education and research into ‘mobility and vehicle design’ at the Industrial Design Centre, Indian Institute of Technology (IIT), Mumbai; and to eventually create a body of specialist vehicle designers, who can address the problems of future mobility and develop research culture in this discipline.

Research is being conducted on making light weight vehicles so as to reduce power consumption further. Integrated single unit reinforced plastic bodies for 2 wheelers and 3 wheelers have been built and tested to achieve this objective. An electric scooter (Fig. 2), which

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**Although the first electricity driven car was driven in 1880s, it lost the race to gasoline-powered vehicles due to the deficiencies of range, weight and time of charging.**

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**Electric Vehicle**

*Fig. 2*

- Single unified Body design in FRP integrating
- Styling Ergonomics, Engineering
- All the components are mounted on the load-bearing FRP body

No metal Chassis Light weight vibration & Fatigue resistance

CTech Labs Pvt. Ltd.  
www.ctechlab.com
weighs less than 40 kg and has a range of about 30 km is one such example. Prototypes of small electric vehicles, like ‘electric auto rickshaws’ and ‘mini 3 wheelers’ (Fig. 3) have been developed to prove the concepts. These concepts can be adopted and developed by ‘research-shy’ companies for manufacture and marketing.

**Design Integration**

Integrating computer and communication technologies with electric vehicles can become a big driver for development. One such example is the development of autonomous road trains for small tourist destinations / archeological locales, which are sensitive to pollution from high traffic. A project is being envisaged at IIT, Mumbai to develop a mobile facility at Elephanta Island, a small tourist spot near Mumbai, for tourists who visit the ancient caves there. An autonomous mini road train running on a battery bank charged through solar panels and following a ‘tour line’ is being contemplated. Besides being a facility for tourists, it offers an additional means of livelihood to the local community that is dependent on tourism. It can be showcased as a prototype for mobility solution in small towns particularly tourist towns.

**Water in Pot Model**

Traditionally the form or physiognomy of a product is dictated by the size of the components, mechanical linkages and their physical fitness. Emerging technologies are fluid in character, and therefore physically pliable. Like water, the usefulness of technology is dependent on the form of the container or ‘pot’ in which it is placed. For example, if water is to be drunk, it has to be kept in a glass or tumbler, and if it has to be poured, it is kept in a jug with a spout; and if it has to be carried, the pot takes the shape of ‘narrow mouthed’ vessel, so that it does not spill and so on. Besides the ‘pot’ has cultural connotations. For example, a teacup is not suitable for drinking water, though it can be used. Modern technology too, like fluid, when placed in a suitable ‘container’ performs better, if the shape of the ‘container’ is designed to suit the situations. Human and contextual issues are the determining factors for design. Major design criteria therefore have to be psycho-physiological, cultural and environmental.

**Unique Form**

Electric vehicles do not need the space as needed for voluminous internal combustion engines or bulky gear trains. The prime movers in electric cars are built into the wheels. The battery pack, particularly the newer polymer batteries are flexible and can be configured according to the availability of spaces and spread, and yet the electric vehicle simply looks like a sedan, or an SUV and even comes with ‘air vents’ in the front. The physiognomy of electric vehicles can be and should be quite different from what we see today in cars or hybrid vehicles. Industrial designers and stylists are working hard to invent a new formal language, which depicts the uniqueness of this breed of products. We have had similar difficulties in the past, when cars were made like horse buggies, and the first TVs were made to look like radios. Indeed with so much interest and so many people inspired to work in this area, the discovery of a new identity or an aesthetic breakthrough for electric vehicles is not a distant dream considering that new conceptual breakthroughs are being driven by the development of new technologies which have fairly matured and moved to the ‘post failure’ stage. The attempts in this direction are worth watching out for.

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The modern world with all its technological advancements, needs power in large quantities today and the requirement is ever increasing. Therefore, the effort to tap renewable sources of energy is being attempted on a war footing. While solar, wind, biomass and other forms are already being tapped across the globe, energies which can be harnessed from the vast oceans is yet to move out from the research arena. Ocean energy can be harnessed in the form of waves, currents, tides and temperature gradients.

When watching waves break at a shore we can see the power they contain, the same power that causes havoc during a cyclone. Currents which are actually water velocities are also constantly present within the ocean.

Ocean Thermal Energy Conversion (OTEC) is a fairly new technology which uses the ocean’s natural thermal gradient to produce energy to drive a power-producing cycle. Considering the fact that the ocean’s layers of water have different temperatures, an OTEC system can produce a significant amount of power. The oceans are thus a vast renewable resource, with the potential to help us produce billions of watts of electric power.

S V S Phani Kumar, M V Ramana Murthy, Purnima Jalihal, M A Atmanand
bodies, though varying in magnitude and direction. While waves and currents contain a fair amount of energy, any structure or equipment to be mounted in the open sea needs to resist these forces to which it is subjected constantly, while generating power. Sea water is also very corrosive, hence materials used should be suitable for long term usage in the sea environment. Another factor is the location on the globe i.e. countries close to the equator have lower winds and wave intensities while those far away have very high wave climates. In India, the average wave power annually is low - though during the monsoon season, for a few months, the waves can be very high.

However being close to the equator and temperatures being high, the sea surface is always fairly warm. The ocean's temperature varies with depth as shown in Fig 1. The profile indicates that the temperature in around 1000m water depth could be as low as 6°C. This difference in temperature between the sea surface and at a deeper depth can be utilised to harness energy. This is called Ocean Thermal Energy Conversion or OTEC. Essentially in OTEC, a fluid with low boiling point is vapourised using the warm surface sea water. This drives a turbine connected to a generator which generates power. The vapour is condensed using the deep sea cold water and in a closed cycle goes back and gets vapourised again. This cycle runs continuously to generate power. Fig 2 shows the OTEC cycle. The main requirement of this process is large quantities of cold and warm sea water. While warm water is available all along the coastline, deep sea cold water is available only at depths of around 800-1000m. The sea bed near the coast drops very gently in India and hence the 1000m water depth is available only around 40-50 kms from the coast necessitating a floating OTEC plant. The OTEC method was attempted in the US and other countries a couple of decades ago, at the time of the oil crisis. Thereafter work was stopped for some years. Today again, many countries have realised that research on OTEC must be given priority.

The National Institute of Ocean Technology (NIOT), Chennai, decided to attempt setting up the first floating offshore OTEC plant of 1 MW off Tuticorin, in the year
The use of LTTD with ocean thermal gradient also results in an environmentally friendly technology because of its use of naturally available heat in the process.

2000. A schematic diagram of the OTEC cycle is shown in Fig 2. A floating plant needs the following complex systems:
- Power module components including heat exchangers and turbine.
- A floating platform with station keeping / mooring to position it in deep waters.
- A long cold water pipe to transfer large quantities of cold water from the depth to the surface.
- Offshore logistics.

All the above systems are facing severe technological challenges, which have not yet been tackled completely. These are briefly discussed below:

Firstly, heat exchangers have to be made of a material suitable to a combination of sea water and a working fluid like ammonia. The design needs to be optimised since the efficiency of the process is low. Using a material like titanium will cause the cost of the heat exchangers to be alone around one-third the capital cost. Thus newer materials also need to be explored.

A big challenge is the floating platform, which has to not only house the power module and plant but has to have good sea keeping characteristics to act as a stable platform throughout the year. Thus, studies towards its responses to severe environmental conditions become important. The OTEC plant’s station keeping or mooring is also an important aspect. The most complex and challenging component is the large cold water pipe for continuous pumping of cold deep sea water for condensing the working fluid. This conduit has to withstand not only the environmental conditions during operations but its assembly and installation are extremely critical.

To attempt to understand the challenges, a non self-propelled barge was built specifically for this purpose at the plant off Tuticorin. All components of the power module were designed, fabricated, assembled and installed on the barge. Parallely a 1 km long pipe with a diameter of 1 m made of HDPE (high density polyethylene) was assembled with the necessary connections at the Tuticorin Port. The pipe was towed around 40 kms off the coast to a deep water location.

However due to lack of suitable infrastructure and handling equipment, there were failures in the cold water pipe deployment. It was therefore decided to attempt desalination using the temperature gradient at shallower waters less than 500 m using the Low Temperature Thermal Desalination (LTTD) method. The process deals with evaporating the warmer surface sea water at low pressures and condensing the resultant pure vapour using deep sea cold water available at about 400m below sea level. The process is found to be simple and easy to maintain since...
it requires just a few components such as a flash chamber for evaporation, a condenser for liquefying the vapour, sea water pumps, vacuum system, a long pipe to draw cold water from 400m below sea level, marine structures such as sump, plant building and the bridge. The use of LTTD with ocean thermal gradient also results in an environmentally friendly technology because of its use of naturally available heat in the process. A schematic diagram of LTTD process is shown in Fig. 4.

A pilot desalination plant with a capacity of 100m³/day was established in the Kavaratti Island of Lakshadweep. The NIOT maintained the plant for one year and handed it over to the local PWD in 2006, which continues to maintain the plant till date. The NIOT put up similar plants in the region and two more plants, in Agatti and Minicoy Islands, each with a capacity of 100 cu m/day that started operations in 2011.

The OTEC barge was also used to demonstrate offshore desalination, where cold water is obtained from about 550m depth using a 700m long and 1m diameter pipeline. The NIOT has developed expertise in the design, assembly and deployment of cold water pipes. Efforts are on to design and build a large scale offshore desalination plant to serve mainland requirements.

Desalination, a spin-off of the OTEC cycle, has been successfully demonstrated. An OTEC plant along with desalination would be an excellent source of clean and green energy and fresh water. However the transfer of power to the shore over large distances to the mainland may not be feasible at this juncture and needs more technological development.

While the basic thermal cycle and the challenges in offshore installations are well understood today, there is a need to optimise the cycle and component design to increase the techno-commercial viability. Cold water from the depths also contains many nutrients and is good for mariculture. Possibility of extraction of some rare earth elements from the large volumes of water is also being studied.

Though the technological challenges are many and demonstration of OTEC for larger ratings is yet to be completed, the country must strive to harness this form of energy due to the large coastline and tropical water temperatures available. This is one of the endeavours being pursued by the NIOT towards the alleviation of the power deficit.

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Today’s fast paced world is overly dependent on energy to fulfill its various requirements related to daily life. Biogas, a clean and renewable source comes as an efficient and cost effective method to generate power. This case study of a biogas bottling plant showcases the efforts of the Ministry of New and Renewable Energy to usher in new technological breakthroughs in the arena of renewable energy.

M. L. Bamboriya
Energy is the key input for the socio-economic development of any nation. Industrialisation, urbanisation and mechanised agricultural techniques have generated a high demand of energy in all forms i.e. thermal, mechanical and electrical. To meet this ever-increasing demand, fossil fuels such as coal, oil and natural gas have been exploited in an unsustainable manner. This exploitation has been posing serious environmental problems such as global warming and climate change. While we have shortage of energy and are dependent on imports in case of petroleum, we are blessed with plenty of natural sources of energy such as solar, wind, biomass and hydro. These sources are environmentally benign and non-depleting in nature and are available in most parts of the country throughout the year.

Biomass resources such as cattle dung, agriculture wastes and other organic wastes have been one of the main energy sources for mankind since the dawn of civilisation. There is a vast scope to convert these energy sources into biogas. Biogas production is a clean, low carbon technology, useful for the efficient management and conversion of organic wastes into clean renewable biogas and organic manure/fertiliser. It has the potential for leveraging sustainable livelihood development as well as tackling local and global land, air and water pollution. Biogas obtained by anaerobic digestion of cattle dung and other loose and leafy organic matter/biomass wastes can be used as an energy source for various applications namely, cooking, heating, space cooling/refrigeration, electricity generation and gaseous fuel for vehicular application. Based on the availability of cattle dung alone from about 304 million cattle, there exists an estimated potential of about 18,240 million cubic meter (m cu m) of biogas generation annually. The increasing number of poultry farms is another source which can generate biogas of 2173 m cu m annually with 649 m birds. In addition, kitchen waste from institutions, universities, restaurants, baraat ghars, industries, parks and gardens in urban and semi-urban areas and even non-edible de-oiled cake from Jatropha and other plants offer a very large potential. These wastes must be treated to ensure reduction in methane emission affecting climatic change and for better environmental conditions. In addition to gaseous fuel, biogas plants provide high quality organic manure with soil nutrients which in turn improves soil fertility, a must for sustainable production and for enhancing productivity. Thus, there is a huge scope for the installation of medium size biogas plants in the country. This can be translated to an aggregated estimated capacity of 8165 MW per day power generation or 22,06,789 LPG cylinders and 21304 lakh kg of urea equivalent or 3974 lakh tonnes of organic manure/fertiliser per day.

Biogas comprises of 60-65 per cent methane (CH₄), 35-40 per cent carbon dioxide (CO₂), 0.5-1.0 per cent hydrogen sulphide (H₂S), and the rest is water vapour etc. It is almost 20 per cent lighter than air. Biogas, like liquefied petroleum gas (LPG) cannot be converted into liquid under normal temperature and pressure. However, after extracting carbon dioxide, hydrogen sulphide and moisture and compressing it into cylinders, it can be made easily usable for transport applications and for stationary applications. Already, compressed natural gas (CNG) technology has become easily available and therefore, bio-methane (or enriched biogas)
which is similar to CNG, can be used for all applications for which CNG is being used. Moreover, purified/enriched biogas (bio-methane) has a high calorific value in comparison to raw biogas.

During the year 2008-09, a new initiative was taken up for the demonstration of the integrated technology-package, in entrepreneurial mode, for installation of medium size mixed feed biogas fertiliser plants (BGFP) for generation, purification/enrichment, bottling and piped distribution of biogas under the Research, Development, Demonstration and Distribution (RDD&D) policy of the Ministry of New and Renewable Energy (MNRE). Such plants, when installed are expected to produce compressed biogas (CBG) of CNG quality standards so as to be used as vehicular fuel in addition to meeting stationary and motive power and electricity generation needs, in a decentralised manner through the establishment of a sustainable business model in this sector. These medium size biogas-fertiliser plants can be set up in various villages, agro / food processing industry zones among other areas of the country. Under the demonstration phase, the Ministry is providing financial assistance for implementation of a certain number of such projects that are following an entrepreneurial mode. So far 21 BGFP projects with an aggregate capacity of 37,016 cu m/day have been sanctioned in ten states - Chhattisgarh, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Madhya Pradesh, Andhra Pradesh, Uttar Pradesh and Rajasthan.

The main components of BGFP are given below:

- Pre-treatment system;
- Biogas generation system;
- Biogas storage system;
- Biogas purification system;
- Biogas bottling system;
- Slurry handling system.

The first biogas bottling project was sanctioned to Ashoka Biogreen Pvt. Ltd, after obtaining the license for filling and storage of compressed biogas in CNG cylinders from Petroleum and Explosives Safety Organisation (PESO), with a capacity of 500 cu m/day at village Talwade, Nashik (Maharashtra) which was commissioned on 16 March 2011. The second biogas bottling project of 600 cu m/day capacity for generation, purification/enrichment, bottling of biogas was sanctioned by the MNRE for Rs. 45.5 lakh Central Financial Assistance (CFA) during the year 2009-10, to Anand Energy at Kalatibba, Ferozepur, Punjab (Fig 1, Table 1). This was commissioned on 17 November 2011 after obtaining required license from the PESO. The biogas generation capacity of the plant is 600 cu m per day. The purity of biogas is about 98 per cent methane and this has been corroborated through tests conducted by the National Accreditation Board for Testing and Calibration Laboratories (NABL). The gas has been compressed to 150-bar pressure for filling in cylinders. This purified biogas is equivalent/similar to CNG.

The upgraded biogas is being filled in CNG cylinders and supplied to support the mid-day meal scheme for cooking food for over 18000 school students in Abohar and its adjoining areas. The slurry of the biogas plant is being sold to farmers to be used as a liquid manure for 

The increasing number of poultry farms is another source and can generate biogas of 2173 m cu m annually with 649 m number of birds. 

The upgraded biogas is being filled in CNG cylinders and supplied to support the mid-day meal scheme for cooking food for over 18000 school students in Abohar and its adjoining areas. The slurry of the biogas plant is being sold to farmers to be used as a liquid manure for kinoa plantations. Field trials have indicated the excellent growth in agro-production and substantial improvements in quality. Further, minimum dropping off of fruits was reported since the use of biogas slurry as manure. This biogas bottling project is projected to replace fuel and manure worth Rs. 40 lakh annually, recovering the full cost of the project within four to five years. The separation and bottling of CO2 and extraction of humic acid from the slurry would further improve viability of biogas bottling plants. The BGFP provides three-in-one solution of gaseous fuel generation, organic manure / fertiliser production and wet biomass waste disposal. The leftover slurry is useful as organic manure / fertiliser for improving soil-fertility. It is non-polluting because it is free from weed-seeds, foul smell and pathogens. It is rich in nutrients such as nitrogen, potassium and sodium (NPK) and micronutrients - iron and zinc. These plants prevent black carbon emissions commonly seen in biomass chulhas. Biogas is an easy and healthy cooking fuel since methane emissions from untreated cattle dung and biomass wastes can also be avoided. The enriched biogas can be bottled in CNG cylinders and used wherever CNG is being used. Since there is no pollution from biogas plants, these are one of the most potent tools for mitigating climatic change and being earth savours.

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Gir breed cows were brought from Gujarat to the goshala named Kamdhenu. The Go-Vigyan Anusandhan Kendra is now home to as many as 90 very healthy cows and 60 calves, all of the Gir variety. It also has around 200 old animals and 10 bullocks. More than 2 to 2.5 tonnes of dung and 10 to 20 kgs of fodder waste and cow urine as per requirement are collected from here, in addition to the production of milk per day.

Capacity of the KVIC biogas plant is 45 cu m. Everyday, input slurry made from 12-14 quintals of cow dung with equal quantity of water is fed through the inlet chamber to the digester of the biogas plant. Biogas so produced is used for preparation of chapatis. It saves about 2 cylinders of LPG each day. In fact this plant is overfed as far as daily slurry feeding is concerned.

The plant has been running successfully from July 2001. It was overhauled in June 2009 as accumulation of silt/mud in the digester with input slurry caused a reduction in the retention time of the input slurry. The problem was sorted out by emptying the digester completely. Such reduction in retention time of the input slurry can cause release of partially digested effluent slurry. Black epoxy paint has

This is the story of a residential higher secondary school run by the Sharda Vihar Jan Kalyan Samiti (SVJKS), situated at Sharda Vihar, Mindori village near Kerwan Dam, Bhopal. There are 584 students and around 100 teachers and staff members residing in the campus of the school. In a centrally located mess near the hostels, everyday, around 4500 to 5000 chapatis are prepared using biogas as the cooking fuel. The distance of the biogas burners in the kitchen, from the improved Khadi and Village Industries Commission (KVIC) biogas plant installed near the goshala is around 200 metres. A high density polyethylene (HDPE) and galvanised iron (GI) pipe line measuring about 250 metres has been used to deliver the gas in the mess, the gen-set room and the pharmaceutical lab of the Go-Vigyan Anusandhan Kendra.

Installation and Commissioning of the Plant
This biogas plant was installed and commissioned under the technical guidance of B P Gupta, MTech, MANIT, with financial assistance from the MNRE, New Delhi, disbursed through the MP Urja Vikas Nigam Ltd. Bhopal and SVJKS Bhopal in July 2001. To begin with around 35

Biogas Plant for a School

An outstanding effort to generate power from a Biogas Power Plant in a residential higher secondary school which has helped this sizeable institution meet its everyday needs from cooking to generating power for running various machines.
been used to paint the gasholder and central guide frame to remove the rust patches and protect the gasholder surface from ill effects of weathering.

**Salient Features of the Plant**

**Rust Prevention:** Rust proofing is done by a water jacket around the digester using lubricating oil / greasing oil that is placed over water surface. This is also for eliminating direct contact of the gas holder with input slurry.

**Rain Water Draining from Water Jacket:** Siphon arrangements have been made for removing the rain fed water from the top of the gas holder to the water jacket so that lubricating oil in the jacket remains undisturbed.

**Provision of Overhead Beam:** Overhead beam structure has been provided for lifting the gas holder out of the digester for regular maintenance of the plant, providing gas delivery through the central guide pipe, free revolving and vertical movement of the gas holder.

**Enhancement of the Life of the Central Guide Frame and Gas-holder:**
- Strengthening of central guide frame for increasing its life by putting reinforcement cement concrete between central guide mild steel (MS) pipe and delivery GI pipe which is concentrically fitted inside the central guide pipe.
- Delivery of biogas through the central guide frame by carrying a GI pipe through central guide pipe and taking it out along one of the I-sections of the cross at the ledge level of the digester for easy moisture removal and eliminating the requirement of about 9 meters flexible pipe bi-annually.
- Provision of scum breaking by vertical mild steel members of gas holder and ensuring its free revolving motion and vertical movement.

**Additional Gas Storage Capacity:** An additional gas storage capacity to avoid wastage of biogas during morning hours until the beginning of food preparation in the kitchen, when the gas holder of the plant is fully raised and is full of gas.

**Utilisation of Additional Biogas if Available:** Charging of a 9.5 KVA dual fuel (diesel+biogas) gen-set for electricity generation at the time of load shedding, is done. During vacations in the institute, the biogas is utilised for the production of medicines using 100 cu ft per hour biogas burners.

**Bio-manure Production:** Manure drying pits have been constructed in adequate number to maintain the drying cycle of the effluent slurry from the digester. So that regular production and storage, packing and supply is maintained. Production of additional manure by processing waste fodder of the goshala through vermiculture is regularly carried out. This plant by now has completed more than 10 years and 6 months of its continuous and successful operation and yet it is as good as new. On the basis of its present condition, it can be predicted that it would complete more than 25 years before becoming defunct.

The two reasons for the success are (i) Proper implementation of biogas technology being disseminated by Ministry of New and Renewable Energy, New Delhi and (ii) the sincere efforts of Hukum Singh Patidar, the Manager of the Institute.
The Tamil Nadu Energy Development Agency (TEDA) organised a two-day international conference and exhibition on renewable energy. RENERGY 2012 was held at the Chennai Trade Centre, Nandambakkam, on 12 and 13 March 2012. The Conference was inaugurated by the Minister for Electricity, Prohibition and Excise, Natham R Viswanathan, in the presence of G B Pradhan, Secretary, Ministry of New and Renewable Energy (MNRE); Ramesh Kumar Khanna, Principal Secretary, Energy Department, Government of Tamil Nadu, Rajeev Ranjan, Chairman, Tamil Nadu Electricity Board, Sudeep Jain, Chairman and Managing Director, TEDA and other senior government officials from the centre and state, to debate, discuss and explore several avenues in this sector.

The conference had over 1300 delegates, with a significant number from abroad, making it the largest renewable energy conference ever held in the country. It was aimed at creating a unique experience for all industry leaders to come on one platform to discuss the various investment opportunities, potential and scope in solar, wind, biomass and newer waste-to-energy technologies, electric vehicles, batteries and other energy efficiency sectors. The exhibition had over 100 companies from all sectors of renewable energy participating in it. Leading companies and organisations included Zynergy, Suzlon, Gamesa, Sun Edison, ReGen Power, Centre for Wind Energy Technology (CWET), Vestas, Bonfiglioli, Greenpeace and others who participated in the exhibition, which attracted over 7500 visitors, making it the largest attended renewable energy exhibition in South India.

The conference hosted talks by leaders and top bureaucrats including Dr Pramod Deo, Chairman, Central Electricity Regulatory Commission (CERC); Satnam Singh, CMD, Power Finance Corporation Ltd.; Abha Shukla, Secretary, Bureau of Energy Efficiency; NS Prasanna Kumar, MD, Karnataka Renewable Energy Development Limited (KREDL); DP Joshi, Director, Gujarat Energy Development Agency; Debashish Majumdar, Chairman and Managing Director, The Indian Renewable Energy Development Agency (IREDA); Anil Agrawal, CEO, NTPC Vidyut Vyapar Nigam Ltd. (NVVN); Dr Gomathinayagam, Executive Director, CWET and Ashok Avasthi, Executive Director, Rural Electrification Corporation Ltd. (RECL) and many others.

Commenting on the conference N R Viswanathan, Electricity Minister of Tamil Nadu said: “RENERGY 2012, we believe will spearhead Tamil Nadu’s growth in the renewable energy sector and open more investment opportunities for new players. We are expecting it to lay a strong foundation for the industrialists and public to understand where we are heading. Tamil Nadu is a leader in wind energy and thanks to the Chief Minister of Tamil Nadu, J Jayalalithaa’s vision, we will soon overcome all bottlenecks.”
In the financial year 2011-12 with the support of the Ministry of New and Renewable Energy (MNRE), the Maharashtra Energy Development Agency (MEDA) organised 3 State level seminars and exhibitions at regional headquarter cities namely Aurangabad, Nagpur and Navi Mumbai. The purpose was to make the people aware about the use of renewable energy and the status and scope of renewable energy at the national and state level. These events really boosted the efforts of the MEDA and the MNRE in creating awareness about the use of renewable energy. The theme of the event was Renewable Energy and Energy Conservation -2011.

**Aurangabad**

Exhibition and Seminar  
(14 – 16 October 2011)

The exhibition was held in the grounds of Hotel VITS with a total of 40 well furnished free stalls put up. The entry was free and it was visited by more than 40,000 persons. There was an attractive live demo of projects and renewable energy gadgets were put up for sale. Ganesh Naik, Minister, Non-Conventional Energy, Maharashtra inaugurated the function.

A one-day seminar was organised on 14 October 2011. More than 300 participants including students from technical and engineering colleges, architects, builders, investors, engineers and others from various industries attended the seminar.

**Nagpur**

Exhibition and Seminar  
(25 – 27 November 2011)

An exhibition was held at the Kasturchand Park Ground, Nagpur with 60 stalls put up for display. It attracted more than 45,000 visitors. Shivajirao Moghe, Minister, Social Justice, Maharashtra inaugurated the function.

A one-day seminar was organised on 25 November 2011 at Hotel Tuli International, Nagpur on ‘Solar Energy Applications and Solar Passive Architecture’ with more than 350 participants from technical and engineering colleges, architects, builders, investors, engineers and among others from various industries.

**Navi Mumbai**

Exhibition, Seminar and EC award distribution ceremony  
(13 – 15 March 2012)

The exhibition was held at Corporation Ground, Navi Mumbai where a total of 70 stalls were put up and it was attended by more than 45,000 visitors. Ganesh Naik, Minister, Non-Conventiona l Energy, Maharashtra inaugurated the function.

Along with the exhibition a one-day seminar was held on 13 March 2012 at hotel Four Points, Vashi, Navi Mumbai, on the theme ‘Power Generation from Renewable Energy Projects and Energy Conservation’ with the participation of around 450 people. A state level Energy Conservation Award distribution ceremony was also organised along with the event. The ‘Thane and Pune Municipal Corporations were given the EC award by Ganesh Naik. Apart from these many other private units were also rewarded for their efforts in the field of energy conservation.

Various companies like manufacturers of solar PV and thermal gadgets, batteries, biomass gasifiers, wind power developers and manufacturers, energy consultants and auditing firms participated in the exhibition. It was also attended by a varied audience ranging from industrialists, and builders to officers, doctors, social organisations and students. The event proved helpful for the people in Marathwada and Vidarbha regions, who appreciated the MEDAs efforts in making renewable energy and energy conservation devices and systems available under one roof and at their doorstep. Expert speakers elaborated upon the importance of the sources of renewable energy and energy conservation and the policies of state and central government. Many manufacturers, developers, distributors, dealers got a good platform for presenting their products to people.
Since 2009, a hydrogen powered street cleaning vehicle has been undergoing testing on the streets of Basel, Switzerland. The project is intended to take 'hydrogen' drives out of the laboratory and onto the streets in order to gain experience on using them under practical conditions. The result of the pilot trial: hydrogen as a fuel for municipal utility vehicles saves energy, is environmentally friendly and is technically feasible. In order to make it cost-effective, however, the prices of fuel cells, pressurised storage tanks and electric drives must all drop significantly.

The hydrogen powered street cleaning vehicle, took about 18 months to develop. "It became clear relatively quickly that the fuel cell system, which had been developed as a one-off, specially for the project, was not yet ready for use in a real-life setting," explains project leader Christian Bach, head of Empa’s Internal Combustion Engines Laboratory. The vehicle has achieved its targets both in terms of energy consumption and performance, the project team -- which, in addition to researchers from Empa and the Paul Scherrer Institute (PSI), also included the vehicle manufacturer Bucher Schoerling, the electric drive specialist Brusa, the hydrogen manufacturer Messer Schweiz, and the city of Basel Environment and Energy Department as well as the city’s cleaning services -- decided to replace the fuel cell system initially used with another more mature product, and also to implement a single centralised safety module. The ‘Fuel Cell System Mk 2’ has now been in operation since the summer of last year and has proven to be far more robust; in fact, only once has it been necessary to take the vehicle out of service, because of a defective water pump.

Despite these setbacks, however, for the past three months, the vehicle has been running so reliably that the city cleaning services are able to use it on an everyday basis as they would a 'normal' vehicle.

The test phase in Basel showed that fuel cells are ready for use under everyday conditions, though currently only in niche applications such as municipal utility vehicles. Their use allows the operator to save a considerable amount of energy, since the vehicle consumes less than half the fuel of its contemporaries. This means that instead of 5 to 5.5 litres of diesel per hour (equivalent to an energy consumption of 180-200 MJ per hour) the hydrogen powered vehicle needs only 0.3 to 0.6 kg of fuel per hour (that is, 40-80 MJ per hour). And in terms of CO₂ emissions, too, the new vehicle performs about 40 per cent better than a diesel powered equivalent, even when the hydrogen is produced by the steam reforming of natural gas using fossil fuels. If the hydrogen was produced using energy from renewable sources then the CO₂ reduction would be even greater.

During use, the novel vehicle has proven to be user-friendly and safe. Refuelling was done by the drivers themselves at a mobile, easy-to-use hydrogen fuel station. An additional advantage is the fact that the fuel cell powered vehicle is much quieter than a diesel vehicle. The only disadvantage, however is, that on cold days, the waste heat from the fuel cell and the electric motor are not sufficient to adequately warm the driver’s cabin -- a typical weakness of electrical drives. The vehicle will undergo further testing in everyday situations in order to gain more operating experience and to allow the ageing behaviour of the various components used in the vehicle to be studied. Currently a vehicle of this kind is about three times as expensive as a conventional one. On the other hand, it is encouraging to know that the costs of fuel cell systems alone have, over the past few years, dropped by a factor of ten, and the end of this trend is not yet in sight. ☞

Hydrogen Power in Everyday Life: Clean and Energy Efficient
ELECTRICITY WITH A MAGNET

Of course you know how a magnet can pick up small metal objects. You can actually make a tack jump to the magnet by holding them close together. Magnetism is a form of energy. It can push or pull things. It can even push or pull some of the tiny particles that make up matter: electrons. And when you push or pull electrons, you get electricity. Let’s try making electricity with a magnet.

**Things you will need**
- 100 cm of bare copper wire
- 1 bar magnet
- 1 electric meter
- 1 cardboard tube

**Steps**
1. Wind the wire around the cardboard tube about 20 times
2. Connect both ends of the wire to the meter.
3. Take the magnet and move it near the coil but not through it. Observe the meter.
4. Move the magnet in various directions around the coil.
5. Move the magnet through the coil, back and forth. Make more than one trial doing this. Try moving the magnet at different speeds. Move the coil over the magnet, keeping the magnet still.

**Now answer the Qs**
1. In which step did the meter move the most?
2. When the meter made the greatest movement, in what direction were you moving the magnet?
3. Was there a difference between moving the magnet through the coil, or moving the coil over the magnet?
4. Was there a difference when you moved the magnet faster?
5. The lines of force on a magnet would look something like this (if we could see them). What happened to those force lines when you moved the magnet inside the coil?
6. Can you figure out some way that you could make the magnet spin really fast inside the coil? Send your answers to the Editor and see your name specially flashed on this page.
Ecars in Ireland
www.esb.ie
ESB established ecars to roll out the charging infrastructure for electric cars and vehicles across Ireland and to support the introduction and demand for electric cars nationally. ESB, as the single owner/operator of the electricity distribution system, is responsible for implementing this across Ireland. ESB ecars’ targets are to install 2,000 home charge points, 1,500 public charge points and 30 fast charge points nationwide.

Renewable Energy World Conference & Expo Africa
www.renewableenergyworldafrica.com
Renewable Energy World Africa Conference and Exhibition 2012, taking place in Johannesburg, South Africa on 6-8 November 2012, have launched their eagerly anticipated website. The website contains important information regarding to exhibiting and sponsorship opportunities, travel and accommodation for the event, registration prices, etc.

Alternative Fuel Vehicle Resale website
www.afvresale.com
The Sales Network (TSN), a provider of niche-marketing solutions, released a new website, designed to aid customers looking to buy and sell previously owned alternative-fuel vehicles and equipment, according to a March 6, 2012 press release. The site provides free membership for listing, responding and searching for pre-owned alternative-fuel vehicles in the US, including those powered by propane autogas, ethanol, CNG, electricity and biodiesel, as well as hybrid vehicles.

Hydrogen and Fuel Cells:
Emerging Technologies and Applications
By: Bent Sorensen
Hard Cover: 512 Pages
Cost: $ 72.08
Publisher: Elsevier Ltd. 2011
ISBN: 978-0-12-387709-3

This book provides a brief ready reference for a hydrogen economy, in which this one gas provides the source of all energy needs and is often touted as the long-term solution to the environmental and security problems associated with fossil fuels. However, before hydrogen can be used as fuel on a global scale we must establish cost effective means of producing, storing, and distributing the gas, develop cost efficient technologies for converting hydrogen to electricity (e.g. fuel cells), and creating the infrastructure to support all this. This text available provides up to date coverage of all these issues at a level appropriate for the technical reader. The book describes the various aspects of hydrogen fuels cells usage along with the obstacles, benefits of its use and the social implications.

Power Conversion of Renewable Energy Systems
By: Ewald F. Fuchs, Mohammad A.S Masoum
Hard Cover: 692
Publisher: Springer 2011
ISBN: 978-1-4419-7978-0

Zero Carbon Energy
Kyoto 2011
By: Takeshi Yao
Hard Cover: 300 pages
Cost: $ 163.17
Publisher: Springer 2012
ISBN: 978-4431540663

Hybrid Electric Vehicles: Principles and Applications
By: Chris Mi, M. Abul Masrur, David Wenzhong Gao
Hard Cover: 468 Pages
Cost: Euro 68.20
Publisher: John Willy & Sons Ltd 2011
ISBN: 978-0470747732011

Renewable Energy Sources and Climate Change Mitigation
By: Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Kristin Seyboth, Susanne Kadner, Patrick Matschoss
Hard Cover: 1088 pages
Cost: $ 183.78
Publisher: Cambridge University Press 2012
ISBN: 978-1107023406
National

3 June 2012
International Conference on Power System Operation and Energy Management, Place: Hotel President, Guwahati, Organiser: IIMT, Bhubaneswar, Contact: Prof. Pradeep Kumar Mallick, +91 8895885152 or icpsoem, @gmail.com, Website: www.interscience.ac.in

26 - 27 July 2012
REACTION 2012 Place: Chennai, Tamil Nadu, India Organiser: Energy Alternatives India Contact: Karthik +91 9944667345 or reaction2012@eai.in Website: www.eai.in/reaction2012/

30 – 31 July 2012
PV Project Development India Summit 2012, Place: New Delhi, Organiser: Solar PV Insider, Contact: +44 (0) 207 422 4307 or laura@pv-insider.com Website: www.pv-insider.com/development-india

International

2-3 July 2012
EWEA Technology Workshop: Analysis of Operating Wind Farms, Place: Lyon, France Organiser: EWEA - European Wind Energy Association, Contact: Tim Robinson, +32 2213 1844, techworkshop@ewea.org, Website: www.ewea.org/techworkshops

21- 27 July 2012
Energy Transition: Expansion and Integration of Renewable Energy Sources, Place: Greifswald and Berlin, Germany Organiser: IKEM - Institute for Climate protection, Energy and Mobility, Contact: Anika Nicolaas Ponder, + 49 (0) 30 4081870-10, Website: www.summeracademy2012.com

13 – 17 May 2012
World Renewable Energy Forum, Place: Denver, Colorado, Organiser: Americal Solar Energy Society, Contact: 303 443 3130 or smasia@ases.org, Website: www.ases.org

24- 26 July 2012
International Conference on Smart Grid Systems (ICSGS 2012), Place: Kuala Lumpur, Malaysia Organiser: International Association of Computer Science & Information Technology (IACSIT), Contact: Ms. Susan Zhang, icsgs@vip.163.com, Website: www.icsgs.org/cfp.htm

25 – 27 July 2012:
Clean Energy Week, Place: Sydney, NSW, Australia Organiser: Clean Energy Council, Contact: Madeleine Brennan, +61 3 9929 4100, Brennan@cleanenergycouncil.org.in, info@cleanenergycouncil.org.au Website: www.cleanenergyweek.com.au
Renewable Energy at a Glance
Cumulative deployment of various renewable energy projects/systems/devices in India

<table>
<thead>
<tr>
<th>Renewable energy programme/systems</th>
<th>Cumulative achievements (as on 31 March 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Power from renewables</td>
<td></td>
</tr>
<tr>
<td>A. Grid interactive power</td>
<td></td>
</tr>
<tr>
<td>Wind power</td>
<td>17352.66</td>
</tr>
<tr>
<td>Small hydro power</td>
<td>3395.31</td>
</tr>
<tr>
<td>Biomass power</td>
<td>1150.10</td>
</tr>
<tr>
<td>Bagasse cogeneration</td>
<td>1985.23</td>
</tr>
<tr>
<td>Waste to power (urban and industrial)</td>
<td>89.68</td>
</tr>
<tr>
<td>Solar power (SPV)</td>
<td>941.28</td>
</tr>
<tr>
<td><strong>Sub total (A)</strong></td>
<td><strong>24914.26</strong></td>
</tr>
<tr>
<td>B. Off grid/captive power</td>
<td></td>
</tr>
<tr>
<td>Waste to energy</td>
<td>101.75</td>
</tr>
<tr>
<td>Biomass (non-bagasse) cogeneration</td>
<td>382.50</td>
</tr>
<tr>
<td>Biomass gasifier (rural and industrial)</td>
<td>150.21</td>
</tr>
<tr>
<td>Aero-generators/hybrid systems</td>
<td>1.64</td>
</tr>
<tr>
<td>SPV systems (&gt;1 kW)</td>
<td>85.21</td>
</tr>
<tr>
<td>Watermills/micro hydel</td>
<td>1877</td>
</tr>
<tr>
<td><strong>Sub total (B)</strong></td>
<td><strong>721.31</strong></td>
</tr>
<tr>
<td><strong>Total (A+B)</strong></td>
<td><strong>25635.57</strong></td>
</tr>
<tr>
<td>II. Remote Village Electrification (villages/hamlets)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9160</td>
</tr>
<tr>
<td>III. Other renewable energy systems</td>
<td></td>
</tr>
<tr>
<td>Family type biogas plants (in lakh)</td>
<td>45.09</td>
</tr>
<tr>
<td>Solar water heating systems-collector area (million sq m)</td>
<td>5.46</td>
</tr>
</tbody>
</table>

kW= kilowatt; MW = megawatt; Sq m = square metre
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www.mnre.gov.in