Intelligent Energy

Green Solutions for Telecom Towers: Part I

Whitepaper

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Introduction

India has approximately 425,000 telecom towers[1] which form the backbone of its telecom market. These towers require about 16.5 billion units of electrical energy[2] and contribute up to 70% to the total operating costs in rural areas and anywhere between 15-30% to the total operating costs in urban areas[3].

Due to an unreliable electrical power grid, tower infrastructure companies use diesel generators, batteries and a variety of power management equipment to back-up the grid and ensure network availability. The growing cost of energy due to increasing diesel prices and concerns over rising greenhouse emissions have caused tower infrastructure companies to focus on better power management methods. Various methods in the categories of demand management, supply management and/or renewable energies are being adopted. The current trial deployments of renewable energy technology (RET) solutions like solar photovoltaic, wind power, biomass and fuel cells across India are proving that each RET has its own challenges and that no single RET provides a silver bullet solution.

This whitepaper focuses on understanding the RET solutions suitable for telecom in India and provides a comparison of the technologies, their characteristics, economics, suitability and limitations. The sequels to this whitepaper will discuss the ground realities of implementing RET solutions across India on a large scale.

Green Telecom Initiatives

Diesel Woes

The lack of adequate electric grid infrastructure in India is restricting other infrastructural developments like telecom, real-estate and transport among others. In excess of 2.6 billion litres of diesel is consumed by diesel generators at telecom towers annually to meet the energy demand-supply gap, emitting 7 million metric tonnes of CO_2[4].

With the recent spectrum reframing from 900MHz to 1800 MHz and upcoming 3G and 4G roll outs, the subscriber base is expected to grow from the current 951 million to over 1 billion during 2013. This growth will require 100,000 more towers to ensure network availability[5].

[1] http://www.gits4u.com/envo/envo31.htm

[2] http://www.eai.in/club/users/miaf/blogs/375

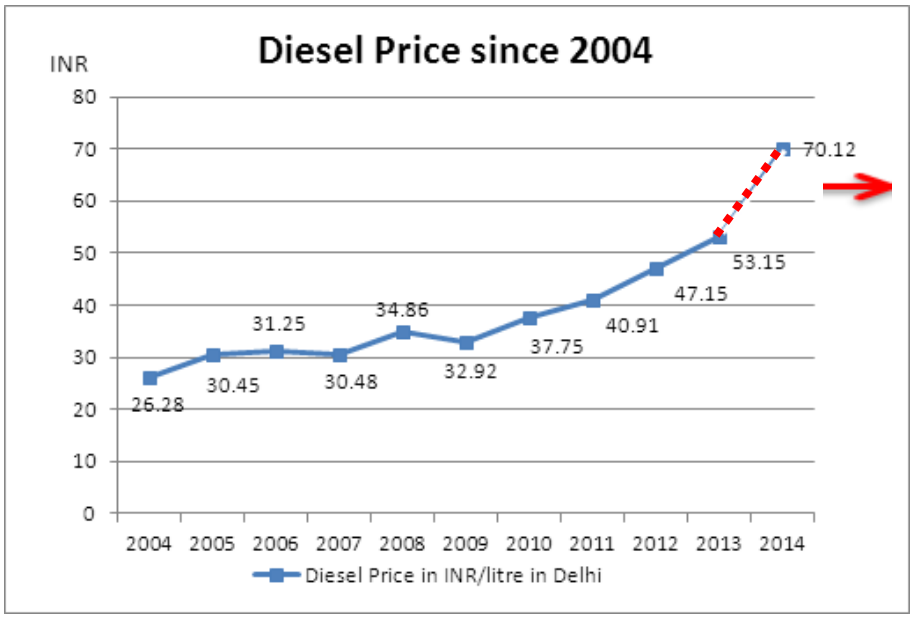
[3] Adoption of Green Technology and Safety of Wireless Network by Milan Jain (Sr. Research Eng. – Converged Network, TRAI).

[4] Assumption – 2.1 litres. Diesel usage per hour and 8 hrs of outage per day for 425,000 towers

[5] http://www.greenpeace.org/india/Global/india/report/Enabling-Clean-Talking.pdf

The price of diesel in India has increased by 45% from INR 32.87/litre in 2009 to INR 47.15/litre in 2012[6]. The recent announcements by the Government allowing state-run oil retailers to raise prices of diesel by up to INR 0.50/litre per month until the end of 2013 will result in further increase of diesel prices to INR 53.15/litre (a total increase of more than 60% from 2009). It is expected that deregulation of diesel prices, if continued with the current regulatory fee, tax structure and marketing margin of oil marketing companies in place, would result in an increase in diesel prices to INR 70.12/litre[7] by 2014, as shown in figure 1. In other words energy costs could constitute greater than 90% of the cost of operating telecom towers, everything else being constant.

Figure 1: Diesel price hike since 2004[8]



Projected price of diesel till 2014 considering the INR 0.50 in crease/litre/month and including marketing margins

Telecom Industry Initiatives

Telecom infrastructure companies are turning to 'green' power management solutions which can be broadly classified into three categories:

- *Demand management (reducing consumption)*

Activities like passive infrastructure sharing, replacement of old base transceiver stations (BTS) with new generation BTS, usage of outdoor BTS, optimized cooling at shelter, usage of intelligent transceivers (TRXs), reduction of air conditioner load by using cold ambient air for shelter cooling and operating air conditioners using stored energy in the batteries to reduce diesel consumption and carbon emission are some of the initiatives that have been implemented so far.

[6] http://www.mypetrolprice.com/2/Diesel-price-in-Delhi

[7] If the Mumbai price is to be considered instead of the Delhi price, the projected diesel price will be higher

8 http://in.reuters.com/article/2011/05/14/india-fuel-idINL3E7GB2E420110514
http://www.mypetrolprice.com/2/Diesel-price-in-Delhi

In the last four years with the evolution of technology, the typical power consumption of BTS has dropped by about 60%[9]. As per Bharti Infratel, introduction of Free Cooling Units (FCU) used in place of air conditioners will contribute to reduction of 4.1 million litres of diesel usage annually after deployment across 6,318 of its 34,220 tower sites.[10]

- *Supply management (increasing efficiency of the power source)*

Technologies like 'Integrated Power Management Systems (IPMS)', variable speed DC diesel generators (DC-DG) and fuel catalysts are few of the solutions that have been implemented to increase power source efficiency.

As per Bharti Infratel's P7 project, fuel consumption for similar load applications in case of DC DGs is approximately 30% lesser than AC DGs. By adopting DC-DGs at 2,000 sites, the consumption of diesel was reduced by 10.18 million litres annually[11].

- *Renewable energy adoption*

Technologies like solar photovoltaic, wind power, fuel cell and other renewable energy sources have been deployed in about 4,021 telecom sites in India[12]. Approximately 1,000 Indus Towers sites use solar photovoltaic[13] to augment the grid and diesel generated power.

The Energy and Resources Institute, a research based institute in Delhi and commonly known as TERI, is focusing its activities in the fields of energy, environment and sustainable development. TERI has been engaged by the Cellular Operators Association of India (COAI) since 2010 to lead efforts in creating a sustainability roadmap for tower companies. TERI will evaluate estimates and guidelines on implementation laid down by the Department of Telecommunications (DoT) to identify issues related to execution and will also provide guidance on technology adoption and rules of execution[14].

The table below showcases a snapshot of the possible diesel savings and corresponding reduction in CO_2 emissions at a telecom tower site using some of the solutions that are currently under trial by the tower infrastructure companies.

[9] http://www.gsma.com/developmentfund/wp-content/uploads/2012/11/COAI.pdf

[10] http://articles.economictimes.indiatimes.com/2012-12-05/news/35620263_1_bharti-infratel-telecom-tower-american-tower

[11] Green Networks: Transforming Telecommunications on Sustainable Energy Alternatives Green Networks: Transforming Telecommunications by Sairam Prasad, CTO, Bharti Infratel on Sustainable Energy Alternatives

[12] http://www.energynext.in/more-4000-mobile-towers-india-powered-green-energy/

[13] http://www.tele.net.in/archive/item/11100-turning-to-renewables-opportunities-and-challenges

[14] http://articles.economictimes.indiatimes.com/2012-07-25/news/32829482_1_rural-towers-urban-towers-tower-companies

Table 1: Typical reduction in CO2 emissions and diesel savings per year per site[15]

Per site per year	CO_2 emissions reduction in tons	Diesel saving in litres	Diesel savings in INR
Passive Sharing	10.5	3,500	1,50,000
Outdoor BTS	4	450	19,000
Next Generation BTS	3.5	450	19,000
Intelligent TRX	2	200	8,500
Solar photovoltaic Energy	8	3,000	1,26,000
Battery Improvements	4	1,500	63,000
DC Diesel Generator	3.5	1,300	54,500
DG Improvements	2.5	900	39,000

Birth of Renewable Energy Service Companies (RESCOs)

The telecom industry's need to achieve economical and scalable solutions for energy management has resulted in the formation of an additional entity in the value chain, called the RESCOs. The RESCOs are expected to design, deploy and manage optimal renewable energy solutions that will help the telecom industry to overcome the energy management challenge.

In the RESCO landscape there are several companies who are working closely with the telecom operators, tower infrastructure companies and tower service providers to jointly develop the best possible solutions that can be deployed economically on a large scale. Single RET companies are either becoming vendors to RESCOs or are transitioning to become RESCOs themselves.

The telecom industry's emphasis on moving away from diesel generators and towards efficient energy management is reflected through the Tower and Infrastructure Providers Association's (TAIPA) invitation for 'Power Purchase Agreement' (PPA)[16] through a request for proposal (RFP).

The Green Power for Mobile (GPM), a Groupe Speciale Mobile Association (GSMA) Development Fund's programme, includes several initiatives such as awareness creation about the renewable technologies for telecom applications, CAPEX and OPEX analysis, vendor mapping and renewable energy market sizing. Below are a few snapshots of current developments[17]:

[15] FICCI – A.T. Kearney report on 'Green Telecom The Way Ahead' (http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/11/COAI.pdf)

[16] http://articles.economictimes.indiatimes.com/2012-05-08/news/31626625_1_indus-towers-tower-arm-telecom-tower)

[17] Green Power for Mobile Bi-Annual Report January 2013 by GSMA

- Through the RFP process TAIPA is deploying 500 green pilot sites using Bio-CNG (compressed natural gas). After completion of implementing the first 500 sites, TAIPA intends a large scale deployment
- Bharti Airtel is deploying around 250 sites using biomass gasification, additionally, an RFP for deploying 3000 solar photovoltaic sites is also being evaluated
- Indus Towers' green city[18] project is in progress to reduce dependency on diesel generators and air conditioners
- Idea Cellular's initiative for green energy aimed to deploy 1,000 sites by the end of 2012. 200 sites were planned for solar hybrid installation where diesel generator would run less than 5 hours a day as compared to earlier 15 to 16 hours, thus reducing fuel consumption. Idea Cellular worked with GSMA to develop biofuel solution for back-up power and have also placed a purchase order for thirty Dantherm fuel cells[19]
- Vodafone is deploying 150 hybrid solar photovoltaic sites, in addition to the 390 sites that are currently deployed

As a new era of RET solutions for telecom arises, it is essential to take a closer look at renewable energy technologies.

Understanding Renewable Energy Technologies

RET solutions like solar photovoltaic, wind power, biomass and fuel cells are the technologies of choice for alternative solutions at telecom towers today. Hybrid solutions that combine diesel generators with RETs and batteries are being customized. Fuel cells are being installed as a standalone solution replacing the existing diesel generator. In a limited number of cases where electrical grid availability is close to 20 hours a day or more, the diesel generator at the tower site has been replaced completely by enhancing the existing battery capacity leading to improvement in economics and reduction of carbon emissions at site. Batteries are a key part of any backup power solutions. A detailed discussion on batteries is beyond the scope of this whitepaper.

Customization of the RET solution for a particular site requires a thorough understanding of each technology and its relevant economics. The comparative characteristics, advantages and limitations of solar photovoltaic, wind power, biomass and fuel cell technologies are discussed below.

Solar Photovoltaic

India receives abundant sunshine for about three hundred days a year. The daily average solar energy incident across India varies from 4 to 7kWh/m^2 considering

[18] http://www.industowers.com/green_cities.php

[19] http://www.fuelcelltoday.com/media/1713685/fct_review_2012.pdf

1000Wh/m^2 of standard sunshine. This translates to 4 to 6 hours of sunshine per day that can be used by a Solar Photovoltaic (SPV) installation[20].

Since a photovoltaic system can only generate power during sunshine hours, it is not feasible to create a standalone solution using this system. Generally, a solar photovoltaic backup power system is:

- Designed in combination with the appropriately sized battery bank, or
- Used to offset the operation of a backup power system like a diesel generator for the approximately four hours per day when sunlight is available.

To configure a solar photovoltaic installation for a telecom tower site, detailed evaluation of the load profile of the site, weather conditions at the site throughout the calendar year, battery efficiency, charge controller efficiency, power loss due to dust accumulation and available area for installation of the solar photovoltaic panels should be considered.

The Ministry of New and Renewable Energy (MNRE) is supporting off-grid solar photovoltaic telecom applications by providing capital subsidy of 30%[21]. India Renewable Energy Development Agency (IREDA) offers soft loans at 5% interest rate for renewable energy projects.

Wind Power

Viability of wind power technology is dependent on the duration of useful wind speed and quality of wind. The wind speed profile varies throughout the year. During January and February the wind speed is at its lowest and peaks through September. The speed reduces from October again. In India quality wind speed is available in states of Maharashtra, Tamil Nadu, Gujarat, Karnataka and in parts of Orissa, Andhra Pradesh and Madhya Pradesh.

With an annual national average of 5-6 m/sec[22] wind speed and an average duration of 4hrs/day[23], the wind power turbine solution for telecom towers cannot form a standalone solution. The dependency on availability of high quality wind speed has made the technology unreliable for less windy sites.

Like solar photovoltaic, regulatory and policy incentives are available for wind power technology which further encourages its application with telecom towers. The incentives include 100% foreign direct investment, 35% accelerated depreciation and exemption of

[20] http://en.wikipedia.org/wiki/Solar_power_in_India

[21] http://panchabuta.com/2012/11/14/solarizing-of-telecom-towers-in-india-could-be-a-2-billion-opportunity-over-next-3-5-years/

[22] Green Energy: A Perspective for Indian Rural Telecom by Pratap Kumar Panigrahi, Sr. Dy. Director General (BW), DoT

[23] Based on Intelligent Energy's interview with Sun n Wind Renewables Pvt. Ltd (http://www.sunnwindhk.com/)

excise duty[24]. MNRE offers 30% capital subsidy for telecom applications up to maximum of INR 1,00,000/kW[25].

Biomass

By definition 'Biomass' is biological material derived from living or recently dead organisms. In India, biomass is used as a primary energy source since millennia in the form of dry wood, leaves and cattle manure. About 32% of the total primary energy used in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs[26]. As of the end of February 2012, 1142 MW[27] of biomass based generation capacity has been installed in India.

In 2008-2009, the Rockfeller Foundation jointly with Indian partners took an initiative to address twin challenges of energy deprivation and poverty through Smart Power for Environmentally Sound Economic Development (SPEED)[28] programme where the need of rural electrification and diesel replacement is integrated with rural community development. As rural electrification and economic development is combined in this initiative, biomass power plants present the opportunity of providing solutions for both. Ministry of Non-Conventional Energy Sources' four Action Research Centres (ARCs) developed gasifiers ranging from 3.5 – 100 kW for telecom and other small capacity applications[29].

There are several incentives, including concessional customs duty on import of machinery and components, excise duty exemption, accelerated depreciation on major components, relief from taxes and capital subsidy for setting up of biomass power projects that are being provided by the government. Besides this, state wise preferential tariff is being provided for sale of power from biomass power plants.

Fuel Cells

Fuel cells convert chemical energy into electrical energy. There are different types of fuel cells that have operating characteristics that are influenced by the type of components used in their design. The various types of fuel cells that can be used for telecom towers are Proton Exchange Membrane (PEM), Solid Oxide Fuel Cell (SOFC) and Molten Carbon Fuel Cell (MCFC). These fuel cells use fuels like hydrogen, methanol, natural gas and other hydro carbons. Fuel cells can run continuously as long as fuel is available and hence make a good standalone renewable energy solution to replace the diesel

[24] India Wind Energy Outlook 2012, GWEC November,2012

[25] Based on Intelligent Energy's interview with Sun n Wind Renewables Pvt. Ltd (http://www.sunnwindhk.com/)

[26] http://www.mnre.gov.in/schemes/grid-connected/biomass-powercogen/

[27] http://panchabuta.com/2012/04/04/biomass-power-generation-installed-capacity-in-india-crosses-620mw-during-11th-plan/

[28] http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/04/therockefellerfoundationspeedprojectinindia-11.pdf

[29] BIOMASS ENERGY IN INDIA:TRANSITION FROM TRADITIONAL TO MODERN by P.R. Shukla (http://www.decisioncraft.com/energy/papers/ecc/re/biomass/bti.pdf)

generator. Fuel cell based systems can be designed to be modular allowing a close match of the installed capacity to the power demand of the site. Additionally, any increase in the demand at the site due to increased tenancy can be met by simple addition of capacity to the fuel cell system. Fuel cells have higher efficiency when compared to other RET solutions. Owing to significantly better efficiency versus load characteristics, fuel cell systems can be used in reduction of the energy requirement of the telecom site in comparison to diesel generators.

Compared to other technologies, fuel cell based solution for telecom towers are relatively new in India. Some trial projects have been undertaken by telecom companies like Idea Cellular and Indus Towers and a few others. While the technology has proven itself through these trials to provide power, the availability and the price of the fuel remains a challenge that needs to be overcome for large scale adoption.

Currently, there are no significant incentives available for this technology in India. However, during the country's eleventh five year plan (2007-12), MNRE had supported projects with more than $15 million irrespective of the industry vertical and for the twelfth five year plan (2012-17) the proposal for hydrogen fuel cells envisions accelerated depreciation, funded field trials for telecom tower back up power[30].

Introducing Renewable Energy Solutions at Telecom Towers

After a brief introduction to various RET solutions, a theoretical analysis for each of the RET solutions for a typical telecom site is presented below to evaluate the solution economics.

Case study

This case assumes an outdoor site with 3 kW load and with 8 hours of grid power outage per day on average.

Table 2: Site Configuration of the Case Study

Case Scenario		
Site Type		Outdoor
Site Load	*kW*	3
Grid Power Availability	*hrs/day*	16
Output Power Requirement	*kWhr/day*	24
Battery Output Voltage	*volt*	48

Based on the above mentioned case assumptions, the site requires 8 hours or 24 kWh/day equivalent of back-up power. The solutions discussed below include a combination of an RET and batteries, thus replacing the diesel generator at site.

[30] http://www.iphe.net/docs/iphe_policy_update_120911_web.pdf

The economics of the solution discuss capital investments of a generic brand of RET and related OPEX based on primary research. Other energy management components at site like SMPS, PIU etc. are considered as constants across all RET solutions comparison.

Solar Photovoltaic (SPV) Solution:

To meet the site off grid energy requirement of 24kWhr/day, the solar photovoltaic solution should be capable of providing 33kWhr/day to account for losses[31]. Assuming average of 4 hours of sunshine per day, an 8kW solar photovoltaic system will need to be installed. It is assumed that, the 8 hours of outage can occur during sunshine availability hours or during non-availability hours. Hence, the battery backup for the site should match the capacity of the solar photovoltaic installation considering non-availability of standard sunshine hours. Site load and the charge current requirement during the sunshine hours determine the battery capacity. Considering average standard sunshine of 4 hours and 30% depth[32] of battery discharge per day, a battery capacity of 1720 Ah @ 48 volts will be required. As per energy requirement of this site the installation area required is 94sq.m.

Table 3: Solar Photovoltaic Solution Specifics

Solar Photovoltaic Solution Specifications		
Avg. Sunshine aviailability	*hrs/per day*	4
1 Kwp SPV Panel generates	*KWh/day*	4
Efficiency Loss		
Charge controller efficiency	%	90
Loss due to dust	%	95
Battery efficiency	%	85

At the current price of INR 100/Wp panel, this installation will cost INR 8,25,593. The batteries will cost approximately INR 5,15,996 totalling to INR 13,41,589 for the solution. It is to be noted here that the system life of a solar photovoltaic system is estimated to be 20 years and that of the battery is 3 years.

The maintenance required on a regular basis includes panel cleaning and charge equalization for the batteries.

Wind Power Solution:

To meet the site off-grid energy requirement of 24kWhr/day, the wind power solution should supply 31kWhr/day to account for losses. If an average of 4 hours of quality wind is available per day, a 1kW turbine will deliver 3kWhr of energy. Hence, a 10kW system will be required. This solution will need a battery storage capacity of 1634Ah @48Volts.

Table 4: Wind Power Solution Specifics

[31] An efficiency of 8.5% in the field has been considered based on Intelligent Energy's interview with various solar companies

[32] Intelligent Energy's interview with solar companies

Wind Power Solution Specifications		
National average wind speed	*m/sec*	3 to 5
Avg. Wind speed availability duration	*hrs/day*	4
Energy production capacity of 1 kW wind turbine	*KWh/day*	3
Efficiency Loss		
Charge controller efficiency	*%*	90
Battery efficiency	*%*	85
Cost of 1 kW wind turbine installation	*INR/ kW*	1,00,000

The total solution cost of INR 14,90,196 includes the wind power generator cost of INR 10,00,000 and the battery storage cost of INR 4,90,196 for the given case scenario. The life of the wind turbine is estimated to be 20 years and the life of a battery is estimated to be 3 years. Like the solar photovoltaic system, the wind turbine system also requires minimal maintenance.

Biomass Solution:

Currently, the smallest available biomass plant in India is that of 10kW capacity. A biomass plant can form a standalone solution as long as biomass is fed to the plant. No battery is required. This system will cost approximately INR 11,00,000. An additional INR 50,000 will be required for the biomass cutter. Maintenance activities include regular cleaning, scheduled repairs and fuel transport.

Table 5: Biomass Solution Specifics[33]

Biomass Solution Specifications		
Biomass power plant capacity	*kW*	10
Biomass requirement	*kg/kWhr*	2
Total area required for 10kW plant	*Sq.m.*	465
Capital cost of biomass plant	*INR/kW*	1,10,000
Biomass cutter cost	*INR*	50,000
Biomass cost (as Fuel)	*INR/kg*	4
Maintainance Cost	*INR/day*	40
Solution Efficiency	*%*	20

Hydrogen Fuel Cell Solution:

To meet the site load requirement of 24kWh/day, a fuel cell of 4kW peak capacity needs to be installed. Since the hydrogen fuel cell solution can run continuously as long as hydrogen fuel is supplied. No additional battery storage is required.

[33] Based on Intelligent Energy's interview with D.E.S.I. Power (http://www.desipower.com/)

Table 6: Fuel Cell Solution specifics[34]

Fuel Cell Solution Specifications		
Fuel Cell stack cost	*INR/kW*	44,000
System cost (Including Balance of Plant)	*INR /kW*	2,20,000
Fuel Cell Efficiency	*%*	40 to 60
Hydrogen Cost	*INR/kg*	450

A 4kW hydrogen fuel cell system costs INR 8,80,000. The energy efficiency of fuel cell is normally ranges from 40-60%[35]. The fuel cell system maintenance includes replacement of stacks and scheduled repairs. The cost of transporting hydrogen fuel is considered as a part of the total fuel cost. The fuel cell stacks will need to be replaced depending on the life of the stack. The fuel cell system's life is estimated to be 15 to 20 years and the stack life is approximately 10,000 operating hours as claimed by several vendors[36].

Table 7: Comparative characteristics of renewable energy solutions[37]

	Solar Photovoltaic	Wind Turbine	Biomass	Fuel Cell
Energy source	Photovoltaic energy generating systems convert sun's energy into electricity	The kinetic energy of wind is converted to mechanical energy and then into electrical energy	Waste matter composed of parts from living or recently dead organisms are used to produce alternative fuels for producing energy	Chemical energy in hydrogen is converted to electricity, water vapour and heat
Efficiency	6.2-19.7%	20%	20%	40-60%
Carbon Foot Print	Zero at point of use	Zero at point of use	Minimal	Zero at point of use
Limitations	1. Dependent on sunshine availability 2. Requires equivalent storage capacity hence needing additional investment 3. large area required for installation	1. Dependent on the quality of wind speed and duration of wind availability requirement 2. Requires equivalent storage capacity needing additional investment	1. Load uptake cannot be limited to telecom, hence need load aggregation from the other source	1. Underdeveloped hydrogen logistics as of date
CAPEX in INR (may vary per brand)	13,41,589	14,90,196	11,00,000	8,80,000
Maintenance	Minimal Maintenance	Minimal Maintenance	Biomass fuel cost and plant maintenance	Hydrogen fuel cost and system maintenance

[34] http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/04/Fuel_Cell_Report_for_fomatting1.pdf

[35] http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf

[36] http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/04/Fuel_Cell_Report_for_fomatting1.pdf

[37] Efficiency numbers are based on information from –
- Solar: Global Technology Trends in Solar PV Power R&D and Commercial by Dr. B Bhargava, MNRE
- Wind: Based on Intelligent Energy's interview with Sun n Wind Renewables Pvt Ltd (http://www.sunnwindhk.com/)
- Biomass: http://zebu.uoregon.edu/1998/ph162/l17.html
- Fuel Cell: http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf

Conclusion

With the formation of RESCOs, the telecom industry is transitioning to renewable energy solutions. With experience from trials, the forthcoming RET solutions will be aimed towards providing the desired economics and deployment scalability considering effective power generation and optimal system integration.

The Government is recognizing and encouraging renewable solutions to overcome the challenges faced by the telecom sector due to increased diesel usage. To strengthen the play of RET solutions, government bodies and relevant telecom associations will need to work hand in hand at a fast pace to bring in the necessary change in the telecom energy consumption landscape.

In the next series of this whitepaper, the ground realities of implementing each of the RET solution at telecom sites will be discussed where the focus would be to determine the solution design, costing, levelized cost of energy (LCOE), on-ground deployment challenges, scalability enablers and inhibitors.

Intelligent Energy would like to acknowledge the contribution of various solar, wind and biomass companies that shared information towards the development of this whitepaper.

About Intelligent Energy

Intelligent Energy delivers efficient and clean energy technology for the global consumer electronics, automotive and stationary power markets – from compact energy packs for mobile devices, to power-trains for zero-emission vehicles, and stationary power units for the always-on infrastructure.

Our unique technology architecture is used by global blue chip companies to create differentiated, cost-efficient fuel cell power systems for mass market applications. It enables Intelligent Energy and our industry partners to solve the challenges of continuous power and productivity, by creating convenient everyday energy solutions to power your life.

Intelligent Energy operates globally, with offices in the Americas, Europe and Asia.

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