Roadmap for demand aggregation of LED lighting

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SHAKTI SUSTAINABLE ENERGY FOUNDATION

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Disclaimer

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Executive summary

Commercialisation of LED lighting in India is a key initiative driven by the Ministry of Power in order to enhance energy efficiency in the general lighting segment. In 2009, a core committee was set up, chaired by the National Manufacturing Competitiveness Council (NMCC), to identify various issues pertaining to the demand for LED lighting, the economics of manufacturing, issues of testing and specifications of LED lighting with possible solutions and recommendations to be dealt with at policy and action levels. The recommendations of this committee were published as 'The economic case to stimulate LED lighting in India' by the Ministry of Power in April, 2010. One of the key recommendations in this report was to aggregate general lighting demand in the country in order to significantly enhance volumes and therefore attract leading manufacturers to India and have the co-benefit of reduced cost.

Subsequently, in order to identify and evaluate potential demand aggregation strategies, the Ministry of Power in association with Shakti Sustainable Energy Foundation initiated a study in February 2011 that attempted to understand the scale of lighting demand in India. The primary objectives of this study are as follows:

- To understand the scale and nature of total space lighting demand for interior illumination in residential and commercial buildings in the country
- To identify and evaluate demand aggregation strategies for increased market penetration of LEDs in lighting applications in the country

The scope of lighting assessment in this study is primarily confined to interior illumination applications in the country. The overall assignment has been broadly divided into the following tasks:

Task I
- Estimation of the total space lighting demand for general illumination and future growth potential

Task II
- Identification of energy savings potential from complete market transformation with LED lighting in general lighting applications

Task III
- Identify and evaluate demand aggregation strategies to accelerate market transformation with LEDs in general lighting applications

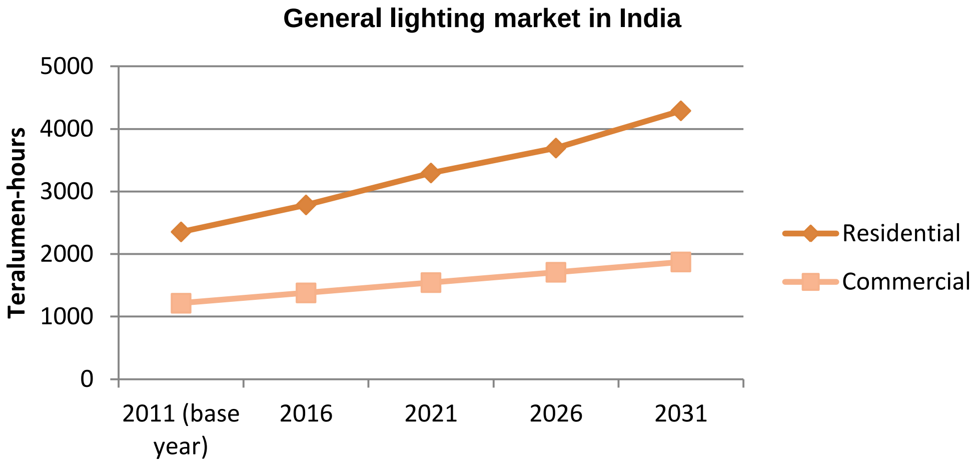
The following sections briefly describe the outcome of these major tasks.

General lighting demand and growth in India

The overall general lighting demand in residential and commercial buildings is estimated as the 'total lighting load' or the 'total wattage of lighting fixtures installed' in the country. The scale of general lighting demand estimated in this report is about 41.54 GW. The residential buildings category contributes about 30.54 GW whereas the commercial buildings contribute 11 GW of this demand.

This report forecasts the national lumen demand for general lighting service in teralumen-hours. The lumen-hour demand in India is poised to increase by approximately 82% in residential buildings and 54% in commercial buildings over the next two decades.

In this scenario of general lighting demand and expected growth in India, energy efficiency in lighting has the potential to achieve tremendous energy savings in the country. LED technology has been globally recognised as super-efficient and eco-friendly in comparison to conventional lighting technologies.



LED lighting in India: Current status and future trend

The market for LED luminaires in India was approximately 320 crore INR in 2011 as per ELCOMA's statistics for the lighting industry. There are about 200 players in the country supplying LED based lighting products. The LED luminaire market in India for general lighting can be broadly divided into two major segments.

LED professional products (luminaires)

The professional products cater mostly to the upcoming floor space or the new construction segment. These products comprise various designs of fixtures for a wide variety of applications. Aesthetic appeal is a key characteristic for these products when promoted to builders. This sometimes may compromise potential energy of reduced application efficiency. However, professional products when integrated with smart controls provide enhanced opportunity of energy savings as compared to replacement or retrofit products.

LED replacement and retrofit lamps

LED replacement lamps are customized retrofit solutions, which replace conventional lamps, for general lighting in the residential and commercial sectors. The replacement of existing fixtures that hold conventional lamps is not an essential component for retrofit solutions. The standard LED replacement tubes can be installed in the existing T12/T8 fixtures after disconnecting the starter and choke electronics. The standard LED replacement bulbs come with both a screw base as well as a two-pin base and can be installed in the standardized incandescent and CFL holders.

The promise of LEDs

LEDs primarily offer advances in efficiency, controllability, and life span. The current luminaire efficacy for warm white LED replacement bulbs available in India is about 70 lm/watt whereas for cool white LED replacement tubes is about 75 lm/watt. The current first cost of warm white LED replacement bulbs available in India is about 100 INR/watt whereas the cost of cool white LED replacement tubes is about 150 INR/watt. The overall expected trend of LED retrofit lamp characteristics is shown in the following table.

LED replacement products may achieve 100 lumens per watt efficacies by 2016 and the same could reach up to 140 lumens per watt by 2021, almost double the current level. The impact in terms of wattage reduction is also estimated in the table. The equivalent wattage of LED retrofit product for 15 watt CFL/60 watt incandescent could reduce to 5 watt from the current average of 9 watt. Similarly, wattages of other LED products could also decrease providing substantial savings in the future.

Characteristics of LED retrofit lamp solutions										
LED retrofit lamp system efficacy projections (lumen/watt)										
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Warm white LED bulbs	60	70	80	90	100	110	120	130	140	140
Cool white LED tubes	70	75	85	95	100	110	120	130	140	140
Wattages of LED retrofit lamps										
Equivalent to 15 watt CFL	11	9	8	7	6	6	5	5	5	5
Equivalent to 52 watt T12 (4 foot)	27	23	20	18	16	15	14	13	12	12
Equivalent to 28 watt T12 (2 foot)	15	13	11	10	9	8	7	7	6	6
Equivalent to 38 watt T8	27	23	20	18	16	15	13	12	11	11
Equivalent to 60 watt Incandescent	11	9	8	7	6	6	5	5	5	5
Equivalent to 30 watt T5	23	21	19	17	16	14	13	12	11	11
Initial cost of LED retrofit lamps (in INR/watt)										
LED retrofit bulb	100	90	80	70	60	50	40	30	20	20
LED retrofit tubes	150	135	120	105	90	75	50	40	30	30
Life of LED retrofit lamps (in hours)										
LED retrofit bulb	25000	30000	35000	40000	45000	50000	60000	70000	80000	90000
LED retrofit tubes	35000	40000	45000	50000	55000	60000	70000	80000	90000	100000

Source: PwC analysis

The annual energy savings and GHG reductions potential from the complete market penetration of general lighting applications, into LED based lighting products, are to the tune of 28,553 GWh and 24.3 million tCO2 respectively. Residential buildings contribute 75% of the national savings potential whereas the commercial sector contributes for the remaining 25% potential. The potential for avoided generation capacity (MW) is to the tune of 20 GW_p in residential buildings and 4.7 GW_p in commercial buildings.

Sector	Energy saving potential in giga watt hours	GHG emission reductions in million tCO2	Avoided generation capacity in GW_p
Residential buildings	22390	19	20
Commercial buildings	6163	5.2	4.7

Lifecycle costing assessment

The lifecycle cost of general lighting lamps can be a useful parameter to assess the overall cost of lamp operation during its lifetime. The lamp wattage, rated life, first cost and replacement cost are the major parameters driving the overall lifecycle cost of a lamp during its operations. The following table shows this assessment undertaken for various conventional lamps and the LED replacement ones normally used for general lighting applications. The assessment shows that the lifecycle cost of the LED retrofit bulb is only 25% of the incandescent lamp and slightly lesser than the CFL in the current scenario. The lifecycle cost of LED replacement tube is currently 70% of the T12 tube and only slightly lesser than the T8 tube. Clearly, the T5 tubes are more efficient than the LED ones in the present scenario. This shows that LED replacement products for T8 and T5 fluorescent tube lamps have a long way to go to prove efficiency and cost-effectiveness. Similarly LED bulbs can also improve substantially such that they can compete with their CFL counterparts in terms of reduced life cycle costs.

Technology	Average lamp system efficacy (in lumens/watt)	Wattage to match desired lumens	Rated life (in hours)	Energy use over lamp operational life (in kWh)	Initial cost (INR)	Replacement cost (INR)	Number of lamps to match LED life	Overall life cycle cost (INR)
ICL	15	60	2000	120	15	15	13	7995
CFL	60	15	6000	90	150	150	4	2400
LED bulb	70	9	25000	225	900	900	1	2025
T12	45	52	5000	260	150	52	8	10914
T8	60	38	8000	304	300	70	5	8180
T5	75	30	10000	300	500	120	4	6860
LED	75	22	40000	880	3300	3300	1	7700

This assessment shows that LED technology is still emerging and there is significant potential for improvement in the efficacy, cost-effectiveness and useful life of LED lighting fixtures. The improvement of these critical parameters will drive the market penetration of LED lighting in the near future.

Roadmap for demand aggregation of LED Lighting in India

Demand aggregation in BPL households

The government of India has recognised BPL household electrification under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) as a key demand aggregation platform for LED replacement lamps in BPL households. In the 11th Plan, each BPL household has been provided with one CFL, free of cost, along with free electricity under the RGGVY. In the 12th Plan, it is proposed to provide an LED retrofit bulb to BPL households instead of CFL. The overall demand for LED retrofit bulbs under this scheme is about 4.14 crore during the 12th Plan period. The overall potential for cumulative reduction in annual lighting load is around 323 MW and the resulting energy savings is 707 million kWh. The annual emission reductions resulting from the expected savings is around 601,000 tCO_2.

The key element for realising the benefits of demand aggregation is a centralised institutional mechanism that can undertake the required bulk procurement of LED retrofit lamps and achieve expected price reductions. In the current model of BPL electrification under the RGGVY, the implementing agencies are the state-owned electric utilities, which seek funding for electrification projects in their respective jurisdictions. There is no provision for demand aggregation in this model. This model has to be corrected to incorporate a centralised institution for procuring LED retrofit lamps for all projects sanctioned within a definite timeframe.

Apart from this, our consultation with ELCOMA has indicated that large volume orders (ideally in millions) have the potential to decrease the prices of LED retrofit lamps by 50 to 60%. However, this is just an indicative limit. The proposed centralised institutional mechanism should test this limit with a pilot procurement size greater than 1 million. This exercise will also reinforce credibility in the perceived benefits of demand aggregation among potential stakeholders.

One should also remember that the current technology of white light LEDs is still in its nascent stage and there is significant scope for improvement in the near future. The current pricing of LED replacement bulbs is high as compared to CFL technology whereas LED efficiency is only slightly higher. The expected reduction in prices and improvement in efficacy in the near future will bring in greater benefits to stakeholders. Therefore, phasing out maximum procurement in the last two to three years of the 12th Plan may improve the financial feasibility of government funds utilised to procure LED retrofit lamps.

The roadmap for demand aggregation in BPL households can be summarised as below.

- Establish a centralised institutional mechanism for procuring LED retrofit lamps for all sanctioned projects within a defined timeframe.
- Undertake a pilot procurement with at least 1 million in volume to test the impact of bulk purchase on LED lamp pricing.
- Phase out the overall target for the 12th Plan, so that the maximum procurement of LED retrofit lamps can be done in the last three years of the 12th Plan.

Demand aggregation in non BPL households

Bundling utility driven DSM programmes through a centralised institutional mechanism is one of the major demand aggregation strategies identified by the Ministry of Power. The objective is to replicate the success witnessed with CFLs that saw 50% reduction in costs and 250 million sales in 2009 from 20 million initially in 2002. In this demand aggregation strategy, utilities may assess the demand for LED lighting separately and the same may be bundled further to increase the geographical scope from utility to state, state to region (a group of states) and region to national level. The demand aggregation can take place through a centralised institutional mechanism (CIM) and the projects may be bid out for aggregated procurement through a competitive bidding mechanism in order to ensure substantial price reductions in the cost of procuring LED lighting. This report has segregated the overall general lighting demand for most utilities in India (excluding some privately owned ones). The general lighting demand is derived from the electricity sales data to domestic consumers. The northern and southern regions have the highest demand for general lighting in the residential sector followed by the western, eastern and north eastern regions.

Utility wise general lighting demand in the domestic sector

Region	Utility	Domestic electricity sales for 2012-13 (in MWh)[1]	Domestic electricity consumption for general lighting (in MWh)[2]	General lighting demand in (MW)[3]
Eastern				
Bihar	BESB	2481	744	510
Jharkhand	JSEB	3718	1115	764
Orissa	CESCO	1949	585	400
	NESCO	921	276	189
	SESCO	708	212	145
	WESCO	900	270	185
Sikkim	Sikkim PD	51	15	10
West Bengal	WBSEDCL	6368	1910	1309
Sub Total				**3513**
North Eastern				
Arunachal Pradesh	Arunachal PD	76	23	16
Assam	APDCL	1289	387	265
Manipur	Manipur PD	180	54	37
Meghalaya	MeECL	271	81	56
Mizoram	Mizoram PD	228	68	47
Nagaland	Nagaland PD	251	75	52
Tripura	TSECL	383	115	79
Sub total				**550**

[1] Extrapolated from the yearly sales data provided in the reports on 'Performance of State Power Utilities for the years 2007-08 to 2009-10 and 2008-09 to 2010-11', by the Power Finance Corporation
[2] Estimated by considering 25-30% of the overall domestic electricity consumption
[3] Estimated by considering 1460 hours of average annual operation of general lighting equipment in Indian households

Region	Utility	Domestic electricity sales for 2012-13 (in MWh)	Domestic electricity consumption for general lighting (in MWh)	General lighting demand in (MW)
Northern				
Delhi	NDPL	3374	844	578
Haryana	DHBVNL	3595	899	616
	UHBVNL	2770	693	474
Himachal Pradesh	HPSEB	1855	557	381
Jammu and Kashmir	J&K PDD	1327	398	273
Punjab	PSEB	9098	2274	1558
Rajasthan	AVVNL	2522	631	432
	JDVVNL	2234	558	382
	JVVNL	4125	1031	706
Uttar Pradesh	DVVN	2129	639	437
	KESCO	1299	390	267
	MVVN	3480	1044	715
	Poorv VVN	5249	1575	1079
	PaschiVVN	5379	1614	1105
Uttarakhand	UtPCL	1650	495	339
Sub total				**9343**
Southern				
Andhra Pradesh	APCPDCL	6797	1699	1164
	APEPDCL	3401	850	582
	APNPDCL	3816	954	654
	APSPDCL	4601	1150	788
Karnataka	BESCOM	5187	1297	888
	CHESCOM	855	214	146
	GESCOM	966	242	165
	HESCOM	1303	326	223
	MESCOM	1173	293	201
Kerala	KESB	7885	1971	1350
Tamil Nadu	TNEB	18704	4676	3203
Pondicherry	Puducherry PD	625	156	107
Sub total				**9471**
Western				
Chhattisgarh	CSPDCL	3997	999	684
Goa	Goa PD	836	209	143
Gujarat	DGVCL	1953	488	334
	MGVCL	1959	490	335
	PGVCL	2879	720	493
	UGVCL	1561	390	267
Madhya Pradesh	MP Central	2161	540	370
	MP West	2502	626	428
	MP East	1915	479	328
Maharashtra	MSEDCL	16011	4003	2742
Sub total				**6126**
Total				**29003**

In this demand aggregation strategy, the state nodal agencies for energy conservation can play an effective role of demand aggregation at the state level. The nodal agencies can bundle several projects across the state and bid out for bulk procurement through a competitive bidding mechanism to ensure substantial price reductions in the cost of procuring LED lighting. The nodal agencies may also test the impact of bulk procurement on LED lamp prices with a pilot procurement size greater than 1 million.

The improvement in LED technology and efficiency in the near future may benefit the LED retrofit bulb market but LED retrofit tubes may take a while to compete with T5 technology. T5 technology may be the dominant choice of lighting by residential consumers in the next four to five years. Therefore, the state nodal agencies need to focus mainly on enhanced penetration of LED retrofit bulbs during the 12th Plan period.

Apart from this, the Bureau of Energy Efficiency may also integrate LED retrofit bulbs into the BLY scheme so that the bulbs may be delivered at the cost of conventional light sources and the difference in first cost may be covered by the sale of certified emission reductions under the Clean Development Mechanism of the Kyoto Protocol. In order to facilitate this, the BEE may develop a separate programme of activities for LED retrofit bulbs that can support private investors in implementing the CDM Programme Activities (CPAs) in India through collaboration with electricity distribution companies (DISCOMs).

Exemption of VAT can also be used as an effective policy tool to reduce LED lamp prices in various states. In some states, LED luminaire products are brought under the highest slab of VAT (at the rate of 14.5%). Therefore, exemption of VAT by state governments could further drive down the costs of LED luminaires beyond the bulk purchase discounts availed through demand aggregation. For an average annual sales volume of 1 million LED luminaires in a certain state in India, the state's exchequer may incur a financial loss of 11.6 crore INR[4] (approximately) by way of introducing VAT exemption for LED luminaires. However, 1 million LED luminaires into the state's grid would reduce the annual lighting demand by 6 MW directly contributing to the state's peak demand reduction. In this regard, the state may also avoid 6.73 MW[5] (approximately) of capacity addition to meet peak demand requirements, clearly translating into 40[6] crore INR of savings in capital investments for power plant infrastructure.

The roadmap for demand aggregation in non BPL households can be summarised as below.

- State nodal agencies for energy conservation must be entrusted with the responsibility for demand aggregation of LED retrofit lighting at the state level.
- Procurement agencies may test the impact of bulk procurement on LED lamp prices with a pilot procurement size greater than 1 million.
- Exemption of VAT can be used as an effective policy tool to reduce LED lamp prices in various states.
- Bulk procurement agencies need to focus mainly on enhanced penetration of LED retrofit bulbs during the 12th Plan period as LED retrofit tubes may take a while to compete against incumbent T5 technology.
- The BEE may develop a separate plan of action for LED retrofit bulbs and integrate LED lighting in the current BLY scheme.

Demand aggregation in commercial buildings

There are no definite strategies for demand aggregation that can result in bulk procurement of large volumes in private commercial buildings. However, the government has considered many policy directives to generate enough demand and accelerate the penetration of LED lighting in commercial buildings. The economic case to stimulate LED lighting in India published by the Ministry of Power in April, 2010, has indicated that the

[4] Sale of one LED retrofit lamp (equivalent to 15 watt CFL) would generate 116 INR by way of VAT imposition (@14.5%); market price of LED retrofit lamps in today's scenario is assumed to be 800 INR per lamp (inclusive of VAT)
[5] Considering 20% T&D losses; 78% PLF; and peak coincidence factor of 0.7
[6] Capital investment in power plant infrastructure is assumed to be 6 crore INR / MW

mandatory legislation for the use of LED lamps by the state and central procurement agencies may generate sufficient scale of demand for LED lighting in public sector owned buildings.

The government may also consider introducing accelerated depreciation benefits (under section 32 Rule 5 of the Income Tax Act 1961) for LED based general lighting systems. This incentive may substantially reduce the ownership cost of LED lighting for commercial purposes and mitigate the high first cost barrier in the current scenario. For an annual national sales volume of 10 million LED luminaires[7] in today's scenario, the country's exchequer may incur a financial loss of 99 crore INR[8] by way of introducing accelerated depreciation for LED based general lighting systems. However, 10 million LED luminaires into the nation's grid would reduce the annual lighting demand by 60 MW directly contributing to the country's peak demand reduction. In this regard, the country may also avoid 67.3 MW[9] (approximately) of capacity addition to meet peak demand requirements, clearly translating into 400 crore INR[10] of savings in capital investments for coal based power plant infrastructure. Apart from these benefits, the scale of annual energy savings would be 88 million units (approximately) and the corresponding annual emission reductions would be 75000 tonnes of CO2 (approximately).

Exemption of VAT by state governments can also reduce the prices of LED luminaires for commercial purposes. Apart from this, the BEE may in time revise the lighting parameters defined in the Energy Conservation Building Code introduced in 2007. The interior lighting power density, which evaluates the total wattage of lighting fixtures per sqm of gross lighted area, is an ideal parameter to regulate the lighting efficiency in commercial buildings.

The roadmap for demand aggregation in commercial buildings can be summarised as below.

- Introduce mandatory legislation for the use of LED lamps by state and central procurement agencies including the CPWD.
- Introduce accelerated depreciation benefits (under section 32 Rule 5 of the Income Tax Act 1961) for LED based general lighting systems.
- Encourage state governments to exempt VAT for purchases of LED luminaires for commercial purposes.
- The BEE may in time revise the lighting parameters defined in Energy Conservation Building Code introduced in 2007.

Demand aggregation in railway and defence establishments

The Indian Railways (IR) has approximately 1 crore lamps providing general lighting for traction (37 lakh), staff quarters (45 lakh) and non traction (18 lakh) purposes. The details of IR infrastructure, general lighting stock and profile of lamps are shown in the following table.

Application type	Existing stock buildings/establishments		Stock and profile of existing lamps
	Value	Unit	
Traction - Passenger coaches	53000	No of coaches	37 lakh T12 linear tube lamps
Non traction - Railway staff quarters	650000	No of households	19.5 lakh T12 linear tube lamps and 26 lakh CFLs

[7] The national sales volume of 10 million LED luminaires is considered for general demonstration
[8] The market price of LED luminaire in today's scenario is assumed to be 800 INR per lamp. Book depreciation is assumed to be 7% under the normal depreciation scenario. The net depreciation under the accelerated case would be 800* INR (80-7%), equal to 584 INR benefit per lamp. The resulting net tax benefit is estimated by considering a MAT rate @16.995%, equal to 99 INR per lamp.
[9] Considering 20% T&D losses; 78% PLF; and peak coincidence factor of 0.7
[10] Capital investment in power plant infrastructure is assumed to be 6 crore INR / MW

Non traction - Service buildings, stations, workshops and railway administrative offices	508200	No of buildings	14 lakh T5 linear tube lamps and 4 lakh CFLs

The following table shows the potential for energy savings and GHG reductions resulting from complete penetration of LED lighting in the IR's general lighting applications.

Parameter/application	Staff quarters	Traction (coach illumination)	Non traction
Cumulative annual reduction in lighting load in (MW)	84	65	18
Annual energy savings (in million kWh)	122	142	53
Annual GHG reductions (thousand tCO2)	104	121	45

The current procurement system for general lighting in the IR is a decentralised system at zonal and divisional levels for service buildings and station premises, production units and workshops. The IR needs to bundle all the general lighting demand across traction and non traction applications and centralise procurement through the Railway Board. The IR has already gained the experience of bundled procurement described above for CFL procurement through a tender floated by the Railway Board in 2008[11]. This tender sought the services of a CFL supplier to supply lamps to a list of nominated consignees in the tender. The supplier had to incur the transport expenses of the CFLs and ensure that the required number of CFLs was received by the nominated consignees within a predefined timeframe. The further distribution of CFLs was entrusted to these consignees. Such a procurement system could be repeated with some refined guidelines incorporating the mandatory standards of performance, domestic manufacturing of LED lighting components, extended warranty periods, etc.

This centralised procurement may be undertaken for its existing lighting stock illuminating passenger coaches (traction). The IR may derive substantial price reductions in LED luminaire prices by bundling existing demand. The IR has also already directed its coach production units and factories to install LED lighting in all its newly manufactured coaches. All the demand arising from manufacturing the new coaches within a short timeframe (in less than 1 year) can be bundled and a centralised procurement can be undertaken through competitive bidding. This can also help the IR in testing the impact of bundled procurement on LED lamp prices.

For non traction purposes, T5 and CFLs already dominate existing stock. As discussed earlier, the improvement in LED technology and efficiency in the near future may benefit the LED retrofit bulb market but LED retrofit tubes may take a while to compete with T5 technology. T5 technology may be the dominant choice of lighting in the next four to five years. Therefore, to replace its existing lighting stock, the IR needs to initially focus on enhanced penetration of LED retrofit bulbs and then wait for the LED retrofit tube market to mature.

Indian defence establishments need to initially quantify existing lighting stock (by technology and application) either by undertaking a survey or through internal directives to all procurement officers. This evaluation will help the Ministry of Defence to assess general lighting demand and further evaluate energy savings potential for LED based lighting. The ministry may further adopt a centralised procurement system for lighting in order to derive substantial price reductions in LED luminaire prices.

[11] Railway Board Tender no. 2008/Elect (Dev)/ 225/9 dated 23.06.08, titled 'Improving energy efficiency in lighting loads in railways' residential quarters over Indian Railway zones, production units and workshops by replacing an estimated number of 26 lakh (±30%) incandescent lamps with compact fluorescent lamps (CFLs) under Clean Development Mechanism in 2008.

The roadmap for demand aggregation in railway and defence establishments can be summarised as below.

- The IR may bundle all lighting demand in its newly manufactured coaches across all production units and workshops and further undertake a centralised procurement of LED luminaires in order to test the impact of bundled procurement on LED luminiare prices.
- The IR may further bundle all existing lighting demand for coach Illumination and further undertake a centralised procurement LED luminaires in order to derive substantial price reductions in LED luminaire prices.
- For non traction purposes, which currently demand only retrofit products, the IR may focus on the enhanced penetration of LED retrofit bulbs and wait for the LED retrofit tube market to mature.
- The Indian defence establishments should initially quantify the existing lighting stock (by technology and application) either by undertaking a survey or through internal directives to all its procurement officers.
- The Defence Ministry may further adopt a centralised procurement system for lighting in order to derive substantial price reductions in LED luminaire prices.

Abbreviations

BEE:	Bureau of Energy Efficiency
BIS:	Bureau of Indian Standards
BLY:	Bachat Lamp Yojana
BPL:	Below poverty line
CDM:	Clean Development Mechanism
CEA:	Central Electricity Authority
CER:	Certified emission reductions
CFL:	Compact fluorescent lamps
CMIE:	Centre of Monitoring Indian Economy
CPWD:	Central Public Works Department
DIT:	Department of Information Technology
DIPP	Department of Industrial Policy and Promotion
DSM:	Demand side management
ECBC:	Energy Conservation Building Code
ECO III:	Energy Conservation and Commercialisation (ECO) Bilateral Project Agreement
EESL:	Energy Efficiency Services Limited
EELE:	Energy efficient lighting equipments
ELCOMA:	Electric Lamp and Component Manufacturers' Association of India
EPS:	Electric Power Survey
ESMAP:	Energy Sector Management Assistance Programme
FOR:	Forum of regulators
FTL:	Fluorescent tube light
GDP:	Gross domestic product
GHG:	Green house gas
GIZ:	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GOI:	Government of India

GTZ:	Deutsche Gesellschaft für Technische Zusammenarbeit
GWh:	Giga watt hour (10^9 watt hours)
HP:	Himachal Pradesh
HPERC:	Himachal Pradesh Electricity Regulatory Commission
ICL:	Incandescent lamps
INR:	Indian national rupee
IRG:	International Resources Group
IRR:	Internal rate of return
ISLE:	Indian Society of Lighting Engineers
LBNL:	Lawrence Berkeley National Laboratory
LED:	Light emitting diode
LPD:	Lighting power density
MOHW:	Ministry of Health and Family Welfare
MOUD:	Ministry of Urban Development
MOSPI:	Ministry of Statistics and Programme Implementation
MSDP:	Multi State DSM Programmes
NMCC:	National Manufacturing Competitiveness Council
NMEEE:	National Mission for Enhanced Energy Efficiency
RGGVY:	Rajiv Gandhi Gramin Vidyutikaran Yojana
Sqm:	Square meter
SSL:	Solid state lighting
TERI:	The Energy and Resources Institute
Tlm:	Tera lumens hours (10^12 lumen hours)
ToR:	Terms of reference defined for this assignment as per the ClimateWorks Foundation
US DoE:	United States Department of Energy
USAID:	United States Agency for International Development

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Background and scope

Commercialisation of LED lighting in India is a key initiative driven by the Ministry of Power in order to enhance energy efficiency in the general lighting sector. In 2009, a core committee was set up, chaired by the National Manufacturing Competitiveness Council (NMCC), to identify various issues pertaining to the demand for LED lighting, the economics of manufacturing, issues of testing and specifications of LED lighting with possible solutions and recommendations to be dealt with at policy and action levels. The recommendations of this committee were published as 'The economic case to stimulate LED lighting in India' by the Ministry of Power in April, 2010. One of the key recommendations in this report was to aggregate general lighting demand in the country in order to significantly enhance volumes and therefore attract leading manufacturers to India and have the co-benefit of reduced cost.

The Table 1 below shows some of the demand aggregation options identified in the report that can bring about a complete market transformation in certain categories of buildings in the country.

The report also recommended that a centralised institutional mechanism (CIM) may be constituted under the chairmanship of Secretary, Ministry of Power with representatives from the MoUD, DIT, the MNRE, the DIPP, the FOR, the BIS, the BEE and the EESL. The mission of such a CIM would be to oversee the design, development and implementation of the demand aggregation programme and put in place a robust monitoring and evaluation process by an independent agency.

Table 1: Demand aggregation strategies recommended by NMCC core committee

Demand aggregation strategy	Consumer category
Integration of LED lighting in the second phase of the RGGVY	BPL households
Integration of LED lighting for households in all villages expected to be electrified by the central power generating stations (which are within 5Km radius)	BPL households
Mandatory legislation for use of LED lamps by the CPWD and other state PWD departments	Public sector buildings
Bundling of utility driven DSM programmes through a central institutional mechanism	Non BPL households

Source: **The economic case to stimulate LED lighting in India,** Ministry of Power, government of India, 2010

Subsequently, in order to identify and evaluate potential demand aggregation strategies, the Ministry of Power in association with the Shakti Sustainable Energy Foundation (herein after referred as Shakti) initiated a study in February 2011 that attempted to understand the scale of general lighting demand in India. The primary objectives of this study were as follows:

- To understand the scale and nature of the total space lighting demand for general interior illumination in residential and commercial buildings in the country
- To identify and evaluate the demand aggregation strategies for increased market penetration of LEDs in the general lighting applications in the country

Shakti appointed PwC to carry out the tasks proposed under this study and the draft report was submitted in July, 2011. The Ministry of Power, along with Bureau of Energy Efficiency, reviewed the key findings of this study and further suggested to include railway and defence establishments as key demand aggregation platforms for LED lighting. The Ministry also suggested segregating the estimates of residential lighting demand among the various states and discoms in the country. The Ministry also suggested consulting with LED lighting manufacturers and suppliers in order to understand the LED lighting value chain, current status of technology, expected trends in the near future and to integrate these findings to assess the financial feasibility of demand aggregation options identified in the draft report.

Scope of the study

The overall assignment has been broadly divided into the three major tasks:

Task I
- Estimation of the total space lighting demand for general illumination and future growth potential

Task II
- Identification of energy savings potential from complete market transformation with LED lighting in general lighting applications

Task III
- Identify and evaluate demand aggregation strategies to accelerate market transformation with LEDs in general lighting applications

Task I: Estimation of the total space lighting demand for general illumination and future growth potential

The scope of lighting demand estimation in this task is confined for general space illumination purposes. The project team has proposed two different approaches to estimate the space lighting demand. The first approach adopts floor area estimates as the basic input parameter and further uses lighting power densities (LPDs) analysed from various building energy audit reports available in the public domain. The space lighting demand is further estimated as the product of the floor area and the LPDs of the respective category of buildings. The second approach is based on the connected load/electricity consumption data collected from the nodal agencies at the national level. The team will further analyse the functional distribution of energy use in the residential and commercial sectors to estimate the lighting demand. Subsequently, the distribution and penetration of lighting technologies in the current lighting market is modelled with appropriate assumptions for estimating the installed base of lighting inventory and stock in the country. The national lighting inventory is further converted to an appropriate metric representing annual lighting service (lumen-hours) forecasted to estimate the future growth potential of the general lighting market in the country.

Task II: Identification of energy savings potential from complete market transformation of general lighting applications with LEDs

In this task, the team will study the current status of LED lighting technology, the value chain of the LED lighting industry, key players in the supply chain and future trends. Secondary resources from the public domain and consultations with experts and stakeholders in the industry will be key sources of information for this task. Further, the team will undertake an assessment of national level potential for energy savings and GHG emission reductions resulting from the market transformation of the general lighting market with LED based lighting applications. The team will also utilise an empirical formula, which relates the consumer penetration characteristics with the relative payback periods, to model the relative penetration of LED lighting in residential and commercial sectors under the influence of market forces.

Task III: Identification and evaluation of demand aggregation strategies to accelerate market transformation with LEDs

Several demand aggregation strategies were already proposed in 'The economic case to stimulate LED lighting in India' published by the Ministry of Power in April, 2010. Railways and defence establishments have been proposed as key demand aggregation platforms recently under the guidance of the Ministry of Power. This task attempts to estimate the overall demand in these strategies and options, and further evaluate the financial feasibility of those strategies by considering the current status and future trends in LED lighting characteristics.

Limitations

The scope of lighting demand assessment in this study is primarily confined to general interior illumination applications in the country. The parameters quantified in this study are dependent on the information derived from a variety of sources available in the public domain. The study does not comment on the quality, scope and reliability of the information derived from these sources. However, while using certain information from the sources in the public domain, the contextual relevance and appropriateness may be discussed that are exclusively based on the judgements of the project team. The report also uses certain market segmentation criteria to segregate lighting parameters quantified in this study (example: residential and commercial sectors). The scope of these sectors may vary significantly across the sources of information available in the public domain. This variation in scope may affect the uniformity in the analysis and estimation of parameters. However, any such variation is neglected for the purpose of simplification in the analysis presented in this study.

Any other limitations are discussed in the following sections whenever and wherever required while detailing the analysis.

Content and organisation of the report

As mentioned earlier, the whole study has been broadly divided into three tasks. The organisation of this report is also aligned with these tasks. The major subtasks under each of these task form the primary chapters in this report. The overall organisation is as follows.

Task I: Estimation of the total space lighting demand for general illumination and future growth potential

1. Space lighting demand for general illumination in India
2. National lighting inventory for general illumination
3. General lighting market in India: Current status and future trend

Task II: Identification of energy savings potential from complete market transformation of general lighting applications with LEDs

4. LED lighting technology: Current status and future trend
5. Energy savings and GHG reduction potential from LED based general lighting solutions

Task III: Identification and evaluation of demand aggregation strategies to accelerate market transformation with LEDs

6. Demand aggregation in BPL households
7. Demand aggregation in non BPL households
8. Demand aggregation in commercial buildings
9. Demand aggregation in railway and defence establishments

Space lighting demand for general illumination in India

Understanding the size and scale of general lighting market in India is fundamental to assess the energy usage in such applications. Many studies in the past have reported the annual sales of general lighting lamps in the country and also the revenue from sale of such lamps in the industry. However this report attempts to quantify other lighting market parameters in the context of assessing the overall energy use for general Illumination in the country. The total wattage of general lighting lamps currently installed in the country is one such parameter. The estimation of space lighting demand in India is a complex web of quantification of parameters involving a very high degree of uncertainty. The rising floor area, economic and industrial growth and many other factors play significant role in driving the space lighting demand in the country. The availability, consistency and reliability of the secondary sources of information pose significant challenges in the development of overall analytical approach.

This report uses two different analytical approaches in structuring and developing the model for Indian space lighting demand. A comparative study of the findings of both the approaches is also carried out in the later part of this report to identify the limitations and relevance of the results for various applications. To simplify the scope of this task, only residential and commercial category buildings are considered for demand assessment. The following sections will detail the methodology and various sources of information adopted in both the approaches to estimate the space lighting demand.

Approach 1: Using floor area and allowable Lighting Power Densities (LPDs)

This approach adopts the total floor area estimates in the commercial and residential building categories as the primary input parameter and further use the average existing lighting power densities in these building categories to estimate the lighting demand, in terms of the total installed wattage of the lighting equipments.

Estimation of total floor area

Commercial buildings

A variety of sources report the floor area estimates for the commercial buildings category in the country (see **Table 2**). However the disaggregation of this floor area estimate into public and private commercial buildings is limited[12].

Table 2: Commercial floor estimates for India

Source	Commercial floor space in million sq m						Compounded annual growth rate	Commercial floor space projected for 2011
	2005	2006	2007	2008	2009	2010		
LBNL, India energy outlook	**860**	885	912	939	966	995	3%	1024.85

[12] In June, 2010 a study ('Total commercial floor space estimates for India') was carried out by the ECO III team with the support of USAID and BEE for estimating the total floor area in the commercial buildings category. Similarly a study by LBNL 'India energy outlook, 2009' also estimates the commercial floor space in India. The floor area estimates calculated by ECO III and LBNL are based on the number of enterprises and establishments reported for various categories of businesses/services in the 'Economic census, 2005' by Ministry of statistics and programme implementation. ClimateWorks Foundation has also completed a study in the past that reports commercial floor space estimates.

ECO III: Total commercial floor space estimates for India	**516**	542	569	597	627	659	5%	691.95
ClimateWorks Foundation	**346**	376	408	442	480	521	8.5%	565.285

Source: Total commercial floor space estimates for India by ECO III

Only the ECO III study has made informed assumptions for the % distribution of commercial buildings floor space among public (26%) and private sectors (74%). Another useful source of information reporting the commercial floor space estimates is the 'Market assessment study for Tri-generation in India' undertaken by DSCL Energy Services Company Ltd in February, 2010. This study commissioned by GIZ has undertaken a review of the commercial floor space estimates reported by various agencies for different categories of buildings in commercial sector (see Table 3)

Table 3: Summary of commercial floor estimates by the GIZ

Market segment	Unit	Floor space		Remarks
		Existing stock (year)	Projected stock (year)	
Private offices[13]	Million sq m	21.04 (2009)	37.16 (2011)	Data for seven majorities have been considered, based on the availability of relevant information
Central government offices[14]	Million sq m	1.24 (2008)	NA	Data correspond to only central government. Data unavailable for state government and municipal offices.
Retail[15]	Million sq m	2.83 (2006)	12.24 (2010)	Represents the organised retail segment only, which comprises 4% of the total retail space
Hotels[16]	Rooms	65,614 (2009)	117,117 (2011)	Includes only 3 star and above rating hotel rooms for 11 cities
Hospitals[17]	Million sq m	36.18: Government (2007) 29.07: Private (2007)	NA	Based on the number of beds and the floor area per bed, as permitted by the Mohawk
Airport[18]	Million sq m	NA	7.25 (2015)	Based on the data for 47 airports across tier-I, tier-II and tier-III level cities

[13] Knight Frank Research: *India Office Market Review, Q 1 2009*
[14] Government of India, Ministry of Urban Development, annual report: 2007-08 (WHICH ANNUAL REPORT DOES THIS REFER TO? PLEASE SPECIFY)
[15] AT Kearney: *Windows of Hope for Global Retailers*, *Indian Retail Market Review Q3 2006 and 2008*, Knight Frank
[16] *India Report: The Voyage: An exploration of key hospitality markets in India* by Cushman & Wakefield
[17] National health profile, 2007, MOHFW,
[18] Airport realty report by Cushman & Wakefield

Residential buildings

For the residential building sector, the total floor area estimate has been calculated based on parameters such as the provisional population totals, the household size and area, derived from various sources in the public domain. Studies conducted by the World Bank, in 2008, quantifying electricity consumption by the residential sector, and the census of India publications between 2006- 11, have provided the critical data for this exercise. For the year 2011, a total of about 9,670 million sq m of residential floor space has been estimated in India (see **Table 4**).

Table 4: Residential floor area estimates

	Population	Total number of households	Total number of electrified households	Total area under electrified households in million sq m
Urban	365030961.2	88550738.2	83060592.4	3903.848
Rural	845162460.8	184159869	110864241	5764.941
Total	1210193422 (as per census of 2011)	272710607	193924833	9668.79

Source: PwC Analysis

The growth rate in the residential building sector has been estimated based on the population and urbanisation projections made by the census of India in 2006 and the World Bank in 2008. The forecasts of the key input parameters, as shown in the Table 5form the basis for estimating the growth in the residential floor space in the country. This also forms the basis for forecasting the space lighting demand in this sector.

Table 5: Population, urbanisation and household size projections

Year	Population ('000 persons)	Urbanisation (% of urban population to total)	Average household size	
			Urban	Rural
2011	1210193.42	30.00	4.1	4.6
2016	1268961.00	31.10	4.0	4.5
2021	1339741.00	32.30	3.9	4.4
2026	1399838.00	33.40	3.9	4.3
2031*	1444110.00	34.60	3.7	4.1

Source: Census of India, 2006, the World Bank, 2008

Lighting power density in residential and commercial buildings

The LPD of a building represents the wattage of the lighting fixtures within the unit lighted area of the building.

$$LPD = \frac{Total\ wattage\ of\ lighting\ fixtures\ (in\ watts)}{Gross\ lighted\ area\ (in\ sqm)}$$

The energy conservation building code (ECBC), 2007, developed by the BEE defines allowable LPDs for different categories of buildings in India (refer to **Table 6** and **Table 7**). The average LPD for different types of commercial buildings or spaces, as defined by the ECBC, is 12.3 watts per sqm, while the allowable LPD estimated for multi-family residential buildings is 7.5 watts per sq m. The LPD is calculated using the following formula:

Table 6: Interior lighting power density: Building area method

Building area type	LPD (watts per sq m)	Building area type	LPD (watts per sq m)
Automotive facility	9.7	Multi-family residential	7.5
Convention centre	12.9	Museum	11.8
Dining: Bar lounge or leisure	14	Office	10.8
Dining: Cafeteria or fast food	15.1	Parking garage	3.2
Dining: Family	17.2	Performing arts theatre	17.2
Dormitory or hostel	10.8	Police or fire station	10.8
Gymnasium	11.8	Post office or town hall	11.8
Healthcare clinic	10.8	Religious building	14
Hospital or healthcare	12.9	Retail or mall	16.1
Hotel	10.8	School or university	12.9
Library	14	Sports arena	11.8
Manufacturing facility	14	Transportation	10.8
Motel	10.8	Warehouse	8.6
Motion picture theatre	12.9	Workshop	15.1

Table 7: Interior lighting power density by the space function method

Building type	LPD (watts per sq m)
Convention centre	12.9
Dining: Bar lounge or leisure	14
Dining: Cafeteria or fast food	15.1
Dormitory or hostel	10.8
Gymnasium	11.8
Healthcare clinic	10.8
Hospital or healthcare	12.9
Hotel	10.8
Motel	10.8
Museum	11.8
Office	10.8
Police or fire station	10.8
Post office or town hall	11.8
Mall or retail	16.1
School or university	12.9
Sports arena	11.8
Motion picture theatre	12.9
Total or average	12.3

The LPDs defined by the ECBC, signify only the allowable values that are theoretically calculated, based on the function and the purpose served by the building. However, the estimation of space lighting demand needs to consider the actual existing LPDs rather than the allowable LPDs. In this regard, Table 8 showcases the average existing LPD estimated for different sectors within the commercial and residential building category.

Table 8: Average existing LPD

Sector	Public commercial	Private commercial	Residential
Average existing LPD (in watt per sq m)	9.07[19]	12.3[20]	3.43[21]
Source	Energy audit studies of the efficient building programme conducted by the BEE	ECBC, 2007	Survey data from the state of Himachal Pradesh

Estimation of space lighting demand

The space lighting demand is calculated in terms of the total installed wattage of lighting fixtures, which is the product of the gross lighted area and the lighting power density (LPD). For simplification of the analysis, the gross lighted areas of buildings coming under the residential and commercial sectors have been assumed to be equal to the average floor area estimated in the previous sections.

Table 9 and **Table 10** showcase the space lighting demand (in giga watt) estimated for the year 2011, for the residential and commercial building sectors in India. Residential buildings contribute 33 GW of space lighting demand, whereas for the commercial buildings sector, three different estimates have been calculated, based on the different sources of floor space information.

Table 9: Total space lighting demand within the residential sector

Sector	Residential
Floor space in sq m	9668788370
LPD in W per sq m	3.43
Space lighting demand in giga watt	33.164

[19] The energy -efficient building programme of the BEE has undertaken energy audit studies for more than 25 commercial buildings within the public sector. These public sector buildings are distributed across different states and come under different functions and building categories such as universities, hospitals, hostels, offices, administrative etc. The average interior LPD derived from this sample of commercial buildings is about 9.07 watts per sq m.

[20] based on the ECBC, 2007 recommendations

[21] For residential buildings, the PwC team analysed the recent survey findings covering around 200 household buildings within the state of Himachal Pradesh. Factors such as the built- up area, lighting load, distribution of lighting technologies and other aspects of lighting have been analysed for all the 200 residential buildings. Based on this analysis, the average LPD estimated is about 3.43 watts per sq m.

Table 10: Total space lighting demand (in giga watt) in commercial buildings

Public commercial	Private commercial	Total commercial	Source of floor space estimates
2.42	9.33	11.74	LBNL, India energy Outlook
1.63	6.30	7.93	ECO III, total commercial floor space estimates for India
1.33	5.15	6.48	ClimateWorks Foundation

For sub-categories of buildings within the commercial sector, the floor area estimates presented earlier, and the allowable LPD estimates based on the ECBC, 2007, have been used in order to determine the space lighting demand. These space lighting demands correspond to the year of the floor area information available for the respective sub-categories of buildings (*refer to* **Table 11**).

Table 11: Space lighting demand in commercial sub-category buildings

Sub-category	Year	Floor space in million sq m	Allowable LPD (watt per sq m) as per ECBC, 2007	Space lighting demand in giga watt
Private offices	2011	37.16	10.8	0.401328
Central government offices	2008	1.24	10.8	0.013392
Organised retail	2010	12.24	16.1	0.197064
Private hospitals	2007	29.07	12.9	0.375003
Government hospitals	2007	36.18	12.9	0.466722
Airport	2015	7.25	10.8	0.0783

Approach 2: Using total connected load and energy use distribution profiles

Under this approach, the total connected load and the functional distribution of the connected load in the residential and commercial building sectors is analysed to model the lighting load estimates. The total connected load is derived from the all India forecasts published by the Central Electricity Authority (CEA), at the national level. The functional distribution of connected load is derived from the load research studies, in the public domain, having large sample sizes in the residential and commercial building categories in the country.

Estimation of total connected load at the national level

The CEA periodically conducts a general review of the power scenario in India, in which it captures the number of consumers and the total connected load for different categories of consumers. The all-India total connected load of residential buildings has been compiled from the general review studies of the CEA. A representation of this compiled data is given in **Figure 1**. Based on the general trend of the connected load, the same has been extrapolated until the year 2011-12, indicating a total connected load of 200 GW in residential buildings sector.

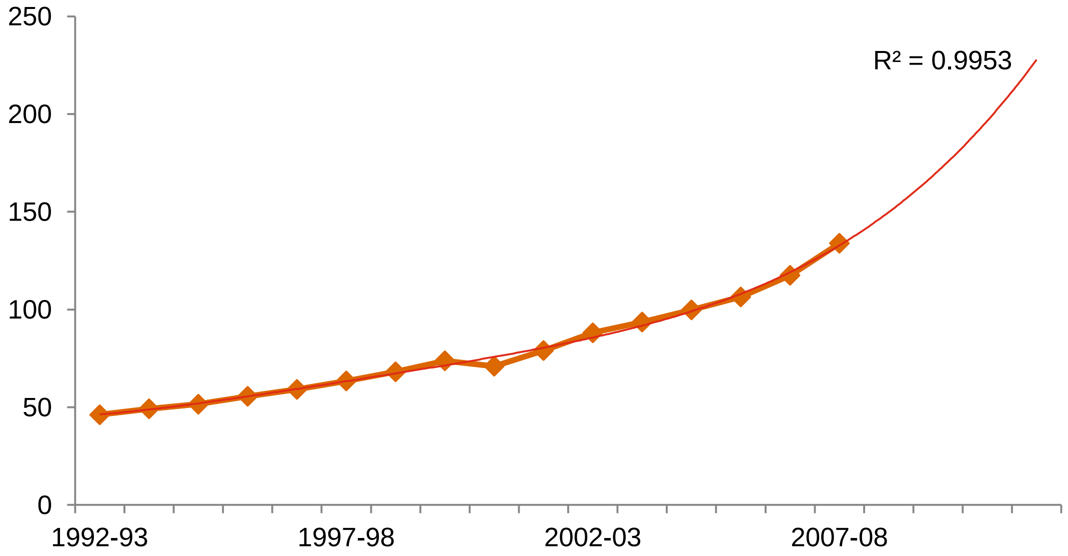


Figure 1: Total connected load in the residential buildings sector

Similarly, the all-India total connected load in the commercial buildings sector has been extrapolated from the general review studies of the CEA, and these projections indicate a total connected load of 55 GW (*refer to* **Figure 2**).

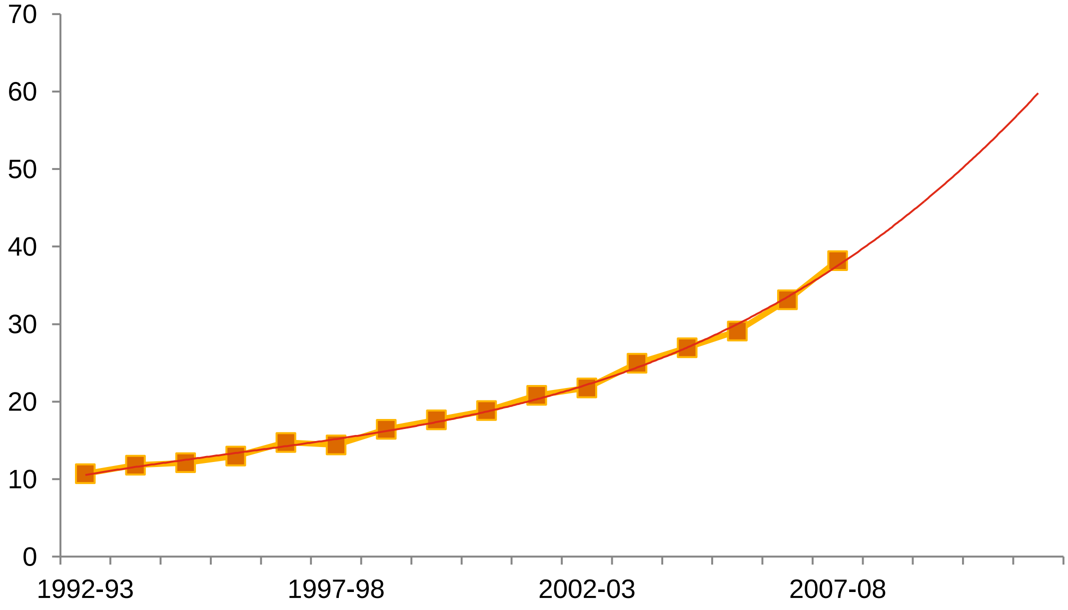


Figure 2: Total connected load in the commercial buildings category

Estimation of lighting load and the space lighting demand

The project team has come across several studies that analyse the load distribution profile, based on the load research surveys for a sample of consumers. However, none of these studies have adopted a sample that is a national representative.

For residential buildings, the most useful source of information towards this purpose, is a report titled, *"Load research for residential and commercial establishments in Gujarat"* prepared by the IRG and the USAID, in consultation with the BEE. This report, which was concluded in March, 2010, undertook a load research survey, targeting 400 residential households within the state of Gujarat. The objective of this study was to understand the end-use consumption patterns of various appliances and evolve a suitable programmatic approach, to be taken up by the state utilities. As per the findings of this survey, the lighting load constituted 5% of the total connected load in residential buildings. Another useful source of information available for residential buildings is the survey data from the state of Himachal Pradesh, which was used to estimate the LPD in the earlier section. Analysis of this survey data shows that lighting accounts for 19.66% of the total connected load.

The per cent share of lighting load derived from the state of Gujarat study may represent the economically developed states within the country, whereas the per cent share derived from the Himachal Pradesh survey may represent the economically underdeveloped states. Further, the estimation of the most appropriate value (per cent of lighting load) is derived from a weighted average calculated, based on the population of the economically developed and underdeveloped states. The corresponding weights derived from the population within the states, as per their economic development, is 0.3 for the per cent share of lighting load from the Gujarat study and 0.7 for the per cent share of lighting load from Himachal Pradesh survey. Thus, the overall weighted average per cent share of lighting load estimated for residential buildings on this basis is 15.27%.

For the commercial buildings sector, the Gujarat study has undertaken a load research survey targeting 200 commercial establishments, where the lighting load constituted 20% of the total connected load (*refer to* **Figure 3**).

Figure 3: Distribution of connected load in the commercial buildings

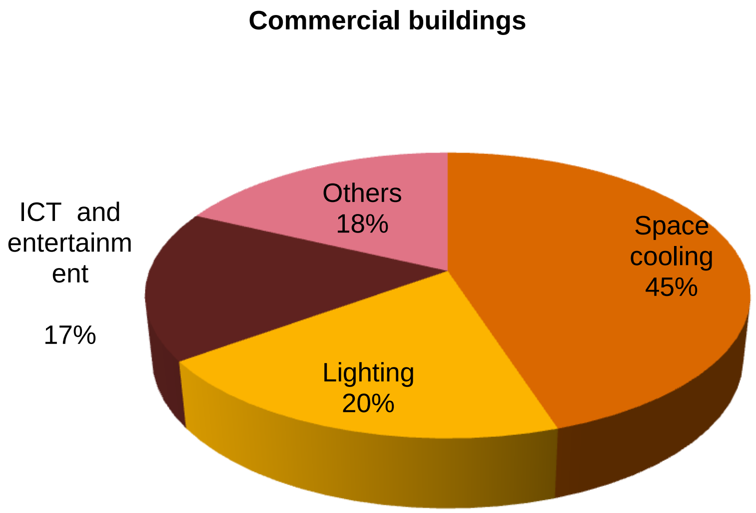


Table 12: Space lighting demand estimation for the year 2011

Sector	Residential buildings	Commercial buildings
Total connected load in giga watt	200	55
Per cent of lighting load	15.27%	20%
Total lighting load and space lighting demand in giga watt	30.54	11

The total space lighting demand estimated using this approach is about 41.54 GW. The residential buildings contribute around 30.54 GW, whereas the commercial buildings contribute 11 GW of this demand.

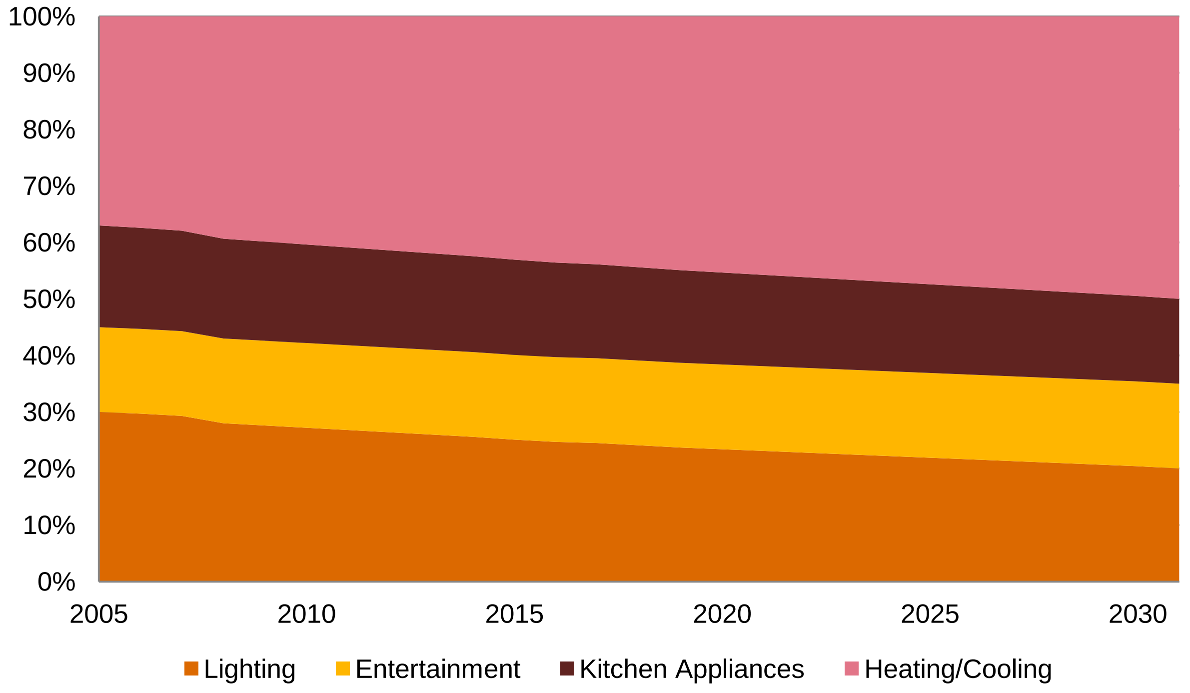
Comparative study of space lighting demand from approaches 1 and 2

Approaches 1 and 2, which have been used to estimate the space lighting demand vary both analytically and also in terms of the scope of the information adopted. For the commercial buildings category, the demand estimated in approach 2 is compared across the four different demand estimates calculated in approach 1 (*see table 10 and 12*). This comparison shows that the demand estimated in approach 1, based on the LBNL floor space information is close to the estimate of the lighting demand calculated in approach 2. Therefore, for the purpose of analysis in the later sections, the space lighting demand estimated in the commercial buildings category would be 11 GW.

For the residential buildings category, the general lighting demand estimated using approach1 is considered more appropriate. This inference is derived by converting the two different lighting demand estimates into energy consumption and further comparing the lighting energy consumption with the similar estimates reported in the literature (refer to **Figure 4**).

For the purpose of analysis in the later sections, the space lighting demand in the residential buildings category would be 33 GW.

Figure 4: Distribution of power consumption by appliances in residential households



Source: World Bank, 2008

National lighting inventory for general illumination

The purpose of this task is to determine the total existing installed base of lighting inventory or stock in the country. This task initially requires a detailed analysis of the penetration of various lighting technologies in today's lighting market. This analysis will also play a key role in forecasting the lighting demand and the development of key policies for further growth of the lighting industry.

The three most useful sources of information in this regard include a recent load research report prepared by the IRG and the USAID in consultation with the BEE in 2010, a load research survey conducted by TERI within the city of New Delhi in 2007 and another load research study initiated by the Himachal Pradesh Electricity Regulatory Commission (HPERC) in 2010. The first report has analysed the penetration of different lighting technologies from the survey covering a sample of 400 residential households and 200 commercial establishments within the state of Gujarat. Among the different lighting technologies found in residential buildings, tube lights account for 55% of the lighting load followed by CFL (29%) and incandescent lamps (16%). Within commercial buildings, tube lights account for 58% of the lighting load followed by CFL (38%) and incandescent lamps (4%).

The load research study conducted by TERI was a case study approach within the city of New Delhi for a sample of 1,000 households in 2007. The purpose of this study was to ascertain the usage and ownership pattern of electrical appliances in households. As per the findings of this study, fluorescent tube lights account for 63% of the lighting load followed by incandescent bulbs (33%) and CFLs (4%).

In the state of Himachal Pradesh, a load research survey was recently undertaken by the state regulatory commission for development of a state -wide DSM regulation. About 200 households and 100 commercial establishments have been surveyed for analysing the end-use appliance consumption and the load patterns. As per the findings of this study, fluorescent tube lights account for 55% of the lighting load in the residential building sector followed by incandescent bulbs (28.7%) and CFLs (16.8%). In the commercial building sector, fluorescent tube lights account for 64% of the lighting load followed by incandescent bulbs (3%) and CFLs (33%).

After reviewing all the three relevant load research studies, the ECO III study in Gujarat and the load research study in the state of Himachal Pradesh (HP) have proven to be the most promising sources of information, revealing the latest facts and updates on the penetration of lighting technologies in the country. For the residential sector, though TERI has analysed the lighting distribution for a sample of 1,000 households, the information presented is relatively old (2007). The lighting technology penetration (in per cent) values, derived from the Gujarat study may represent the economically developed states in the country, whereas the per cent penetration values derived from the Himachal Pradesh survey may represent the economically underdeveloped states. Further, the estimation of national level lighting stock is derived from a weighted average per cent of penetration calculated, based on the population of economically developed and underdeveloped states. The corresponding weights derived from the population in the states as per their economic development is 0.3 for the Gujarat study and 0.7 for the Himachal Pradesh survey. For commercial buildings, the findings of only the Gujarat study have been considered. Figure 6 highlights distribution of lighting stock within the residential and commercial building sectors estimated as discussed. The lighting profile data shown in these figures are further used in the calculation of the national lighting stock as illustrated in table 14 and 15. The subsequent columns in these tables showcase the normal wattage per lamp and the total demand (in kW) for various lighting technologies. The wattage considered includes the losses in the ballast. The total stock of fixtures in the country is calculated based on the penetration levels and the total lighting demand (in kW) estimated for residential and commercial buildings in the previous sections.

Figure 5: Penetration of lighting technologies in residential buildings

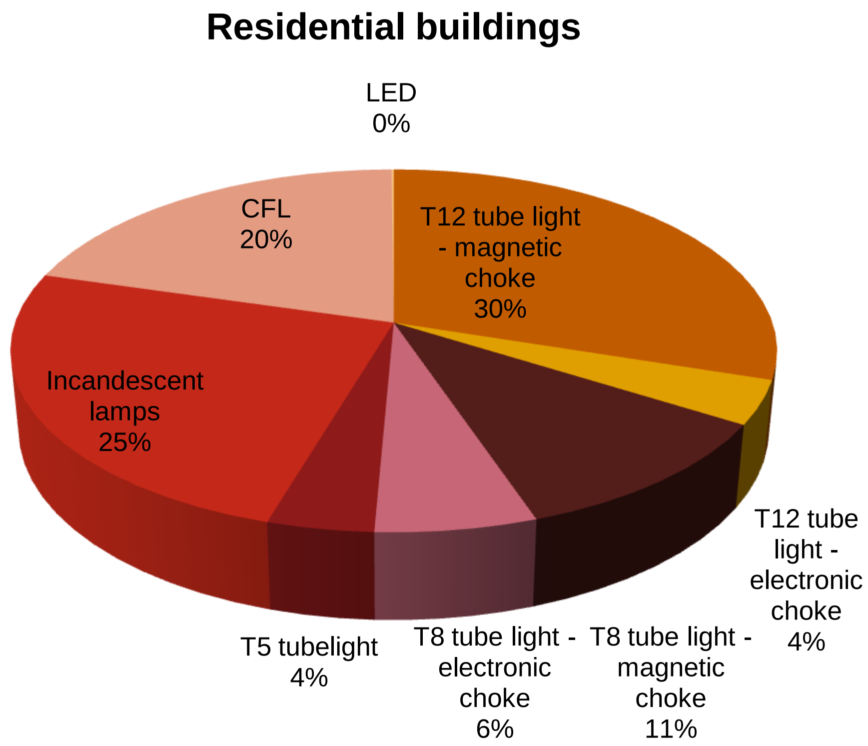
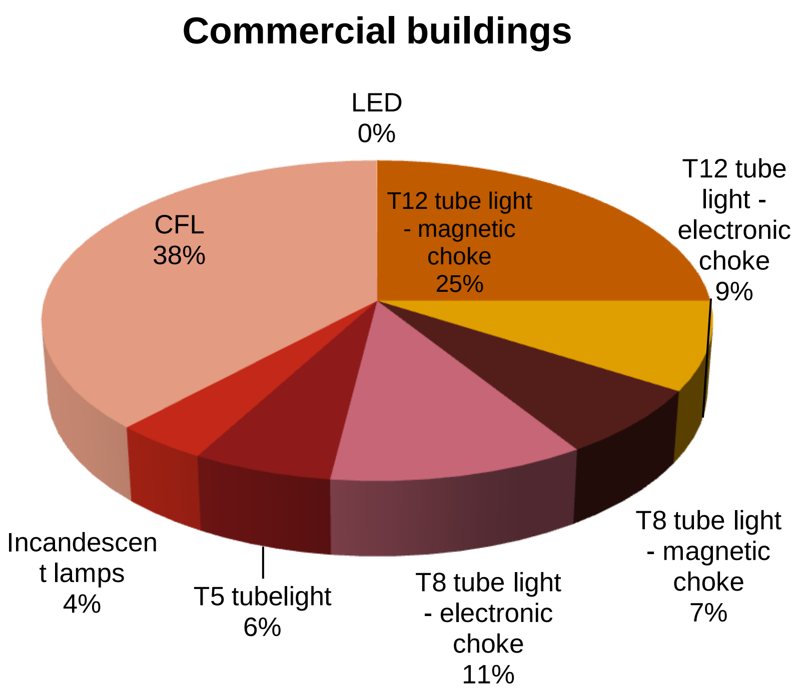
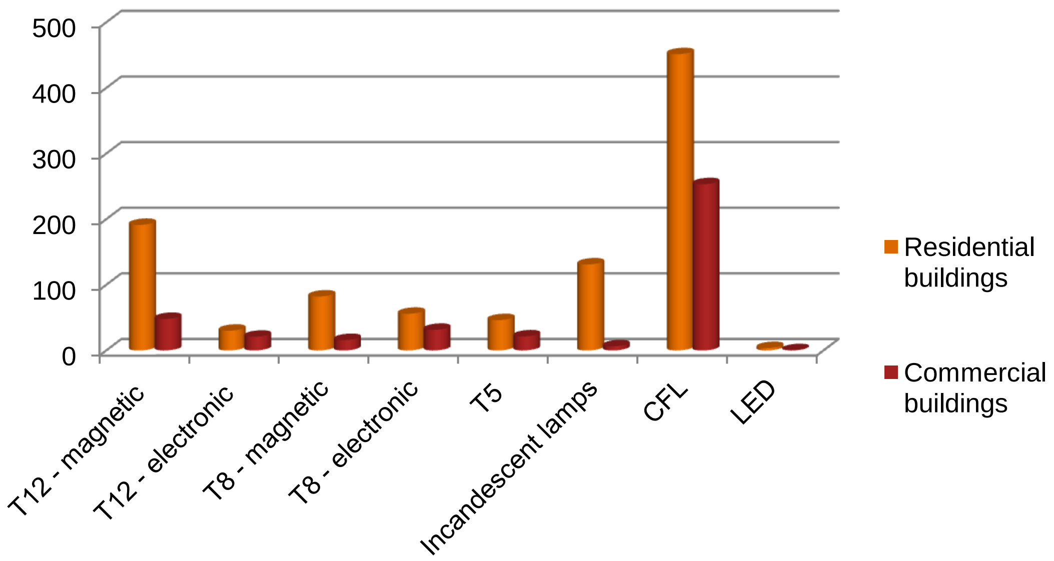


Figure 6: Penetration of lighting technologies in commercial buildings



In residential buildings, a total of 990 million lighting fixtures have been estimated with 450 million stock of CFLs, 406 million stock of fluorescent tube lights and 138 million stock of incandescent lamps. In the commercial buildings category, a total of 394 million lighting fixtures have been estimated with 250 million stock of CFLs, 134 million stock of fluorescent tube lights and 6 million stock of incandescent lamps. Figure 7 shows the present national lighting stock of various technologies in these sectors.

Figure 7: National lighting stock in millions



Further, using the above estimated lighting inventory, this study applies average efficacies, wattages, and operating hours in order to convert the national lighting inventory into lumen-hours of lighting service in each sector (residential as well as commercial buildings). Subsequently, holding the lumen demand per square meter constant within each sector, the lumen demand will be forecasted using the percentage change in square meters of floor area projected in the earlier sections.

Table 13: National lighting inventory in residential buildings

Technology	General specification	Share in load	Normal wattage per fixture (in watts)	National demand in kW	Stock of fixtures (in millions)
T12 tube light : Magnetic choke	Single lamp with ballast - 4 feet	30.0%	52	9,949,183	191
T12 tube light :Electronic choke	Single lamp with ballast - 4 feet	3.9%	43	1,293,394	30
T8 tube light : Magnetic choke	Single lamp with ballast - 4 feet	10.9%	44	3,614,870	82
T8 tube light :Electronic choke	Single lamp with ballast - 4 feet	5.9%	38	1,956,673	51
T5 tube light	Single lamp with ballast - 4 feet	3.9%	30	1,293,394	43
Incandescent	General service lamp	24.9%	60	8,256,755	138

CFL	Equivalent to 60 W incandescent	20.4%	15	6,771,566	451
LED	Equivalent to 60 W incandescent	0.1%	11	33,164	3
Total		**100.0%**		**33,163,944**	**990**

Table 14: National lighting inventory in Commercial buildings

Technology	General specification	Share in load	Normal wattage per fixture (in watts)	National demand in kW	Stock of fixtures (in millions)
T12 tube light : Magnetic choke	Single lamp with ballast - 4 feet	25.0%	52	2500000	48
T12 tube light : Electronic choke	Single lamp with ballast - 4 feet	9.0%	43	900000	21
T8 tube light : Magnetic choke	Single lamp with ballast - 4 feet	7.0%	44	700000	16
T8 tube light : Electronic choke	Single lamp with ballast - 4 feet	11.0%	38	1100000	29
T5 tube light	Single lamp with ballast - 4 feet	6.0%	30	600000	20
Incandescent	General service lamp	4.0%	60	400000	7
CFL	Equivalent to 60 W incandescent	38.0%	15	3800000	253
LED	Equivalent to 60 W incandescent	0.0%	11	4000	0.36
Total		**100.0%**		**11000000**	**394**

General lighting market in India: Current status and future trend

This analysis determines the present annual lumen demand for general lighting (in teralumen-hours[22]) and then groups this demand into various bins represented by different lighting technologies. The baseline demand is then divided by the total building floor space to ascertain the lighting demand per square metre of building space. Lighting demand per square metre is then held constant in each sector, and the total national lumen demand is forecasted over the analysis period, using floor space growth estimates for the residential and commercial building sectors.

Baseline lighting demand in lumen hours

For each of the lamp types mentioned in the national lighting inventory, the total installed lamp wattage, the annual average operating hours and their respective lamp system efficacies are multiplied to convert the national lighting demand into an annual lighting service demand (in teralumen-hours).

Table 15: Estimation of baseline teralumen-hours of annual lighting service in residential buildings

Technology	National demand (in kW)	Hours of use per day	Lamp lumen efficacy (in lm per W)	Annual lighting demand (in teralumen-hours)
T12 tube light : Magnetic choke	9949183	5	45	817
T12 tube light : Electronic choke	1293394	5	55	130
T8 tube light : Magnetic choke	3614870	5	50	330
T8 tube light : Electronic choke	1956673	5	60	214
T5 tube light	1293394	5	75	177
Incandescent lamps	8256755	3	15	136
CFL	6771566	3.7	60	549
LED	33164	3	60	2
Total	**33163944**			**2355**

Table 15 and **Table 16** present the data used for various lighting technologies in the baseline inventory. The average operating hours and the lamp efficacy are primarily extracted from the LBNL study 2010, TERI load research study 2007, the US DoE 2010, some stakeholder consultations and also through significant secondary research from major lamp manufacturer catalogues. A total of 3,569 teralumen-hours of annual lighting service have been estimated within residential and commercial buildings in the country.

[22] Due to the magnitude of calculated national lumen demand, the notation 'tera' is used, meaning 10E+12 (1,000,000,000,000) lumen-hours of annual lighting service.

The teralumen-hours of lighting service calculated has been further classified and apportioned into three technology bins. The technology bins are created to group together the annual lighting demand according to the lighting service quality. **Table 17** shows the baseline annual lighting service demand estimated for the grouped technology bins.

Table 16: Estimation of baseline teralumen-hours of annual lighting service in commercial buildings

Technology	National demand (in kW)	Hours of use per day	Lamp lumen efficacy (in lm per W)	Annual lighting demand (in teralumen-hours)
T12 tube light : Magnetic choke	2500000	8	45	329
T12 tube light : Electronic choke	900000	8	55	145
T8 tube light : Magnetic choke	700000	8	50	102
T8 tube light : Electronic choke	1100000	8	60	193
T5 tube light	600000	8	75	131
Incandescent lamps	400000	3	15	7
CFL	3800000	3.7	60	308
LED	4000	3	60	0.26
Total	11000000			1214

Table 17: Baseline annual lighting service in teralumen-hours for 2011

Technology Bin	Incandescent	Fluorescent	Compact fluorescent	LED	Total
Residential buildings	135.62	1668.05	548.70	2.18	2355
Commercial buildings	6.57	899.36	307.91	0.26	1214
Total	142.19	2567.41	856.61	2.44	3569

National lumen demand projection

The lumen-hour demand calculated by sector and technology bin is projected over the analysis period in order to estimate the growth in lighting demand between 2011 and 2031. The lumen-hour demand calculated in 2011 is divided by the cumulative national floor space for each sector in order to determine a lumen-hour of lighting demand per square metre of building space. Then, the projections for square feet of building growth by the sector are used to project the lumen-hour demand from 2011 to 2031, holding the lumen intensity per square metre constant. This assumption is based on the premise that in the future, people occupying a space will continue to expect today's luminance levels and duration of service. For the residential sector, the annual lighting service in 2011 is approximately 244 kilo lumen-hours per square metre, whereas for the commercial sector the same is almost five times higher with 1100 kilo lumen-hours per square metre *(refer to* **Table 18**). The lighting service is higher due to longer operating hours and higher levels of illumination in commercial floor space compared to its residential counterpart.

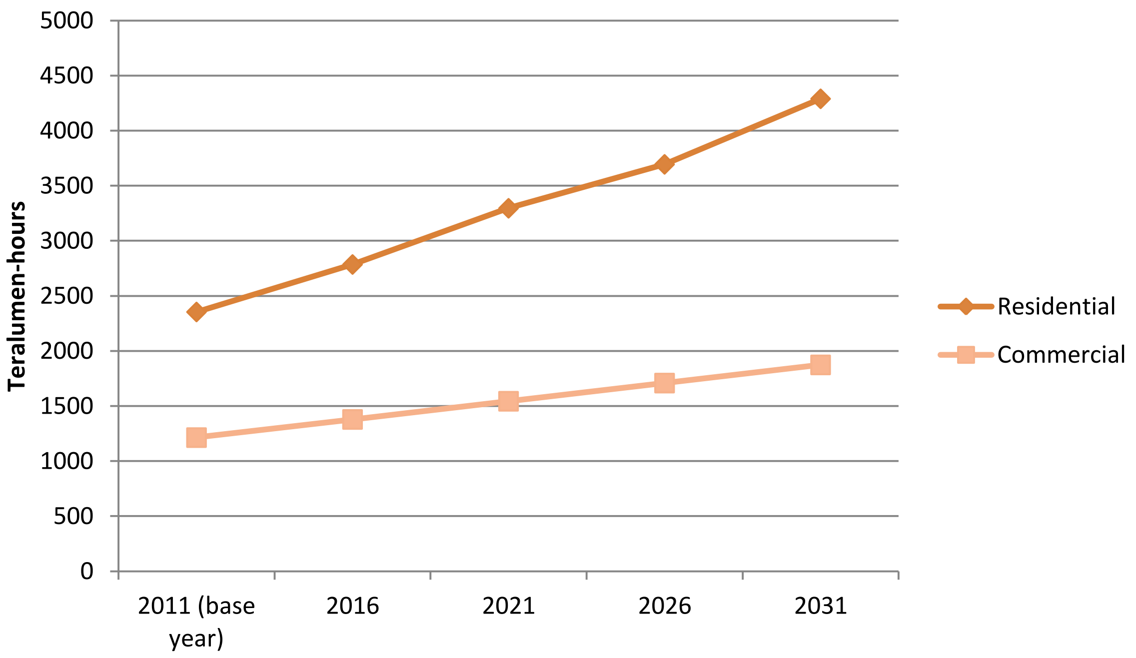
Table 18: Estimation of annual lighting service intensity for year 2011

Sector	Existing floor space (in sq m)	Existing annual lighting service (in teralumen-hours)	Annual Lighting service intensity (in kilo lumen-hours per sq m)
Residential buildings	9668788370	2,355	244
Commercial buildings	1103760000	1,214	1,100

The annual average growth estimates of floor space in the residential and commercial sectors are used to project the increase in lumen demand moving forward. The residential floor space increase is projected for every year over the 20-year analysis period and the commercial sector floor space increase is projected to increase at 30million sq m over the analysis period.

Figure 8 illustrates the national lumen-hour demand growth in teralumen-hours per year by sector, which grows steadily over the analysis period of 2011 to 2031. By this account, lumen-hour demand in India is estimated to increase by approximately 82% in residential buildings and 54% in commercial buildings, over the next two decades.

Figure 8: National lumen demand forecasting in teralumen-hours



The lumen-hour demand estimated for both the present as well as future scenarios form a critical input for further analysis of the lighting market in the country. The scale of annual lighting service (in terms of lumen-hours) contributed by various technologies in the present day's scenario is fundamental in order to understand and quantify the ways in which the lighting market may respond to the influx of new energy- efficient technologies.

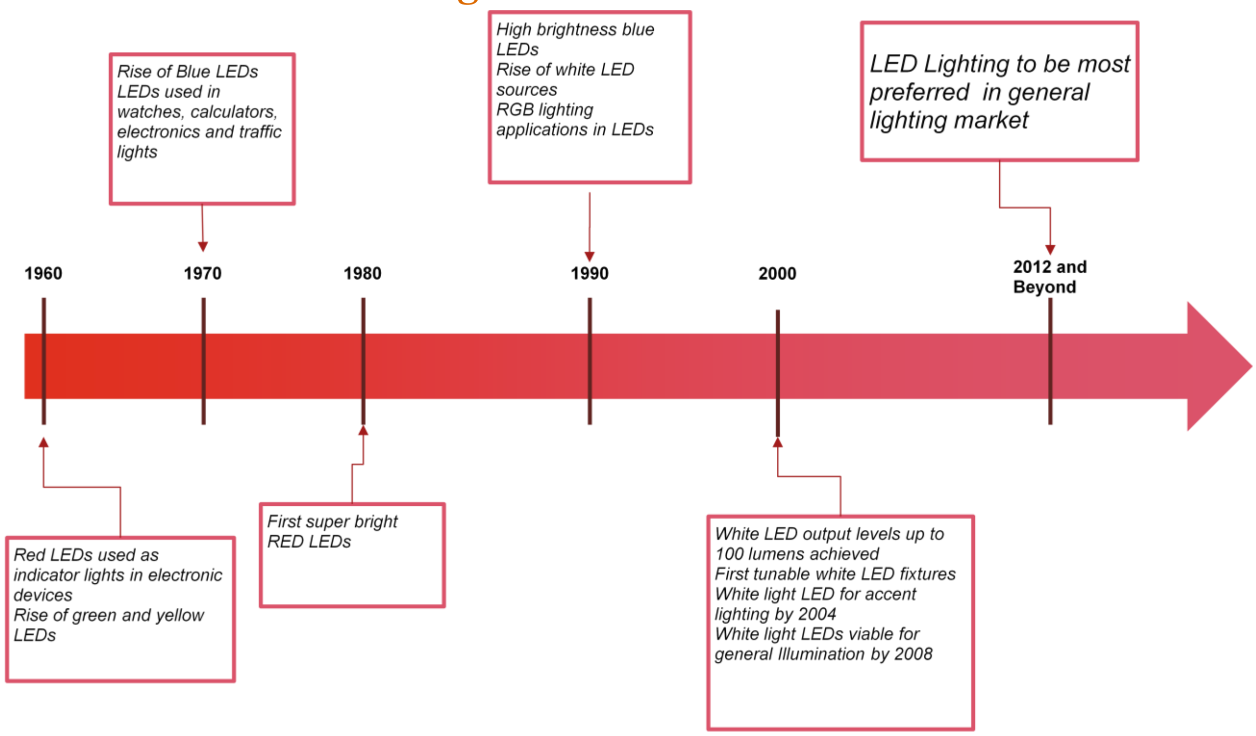
LED lighting technology: Current status and future trends

Light-Emitting Diode (LED) is a semiconductor light source.

> ***LEDs are discrete semiconductor devices with a narrow-band optical emission that can be manufactured to emit in the ultraviolet (UV), visible or infrared regions of the spectrum[23]***

The first LED was developed in 1927 by the Russian Oleg Vladimirovich Losev which emitted light in the infrared spectrum. However, no practical use of the discovery was made till several years later. In 1962, Nick Holonyak Jr. fabricated the first LED capable of emiting light in the yellow spectrum of the visible light. He is credited to be the 'father of the light-emitting diode'. Ever since, the LED has been used as an indicator in several appliances. Over the years,technological developments have permitted using LED for traffic lights, remote controls, aviation lighting, etc. LEDs usage in general space illumination for residential and commercial buildings has gained pace in recent times.

The evolution of white light LEDs



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[23] SSL R&D, Multi Year Programme Plan, EERE, US DoE, April, 2012

How LEDs produce light[24]

Light is the visible portion of the electromagnetic radiation spectrum, encompassing wavelengths from 450 nano-meters (blue light) to 674 nano-meters (red light). The photon is a tiny packet of electromagnetic radiation that we see as light. The lumen is the primary unit of light measurement travelling across a defined space, as perceived by the human eye.

The light that LEDs produce comes from surplus electrons that race energetically towards quantum holes across the border in a sandwich of two different semi-conductor materials. One such material is N the negative semiconductor, usually silicon, which has too many electrons due to the make-up of a special impurity in its lattice. The other is, P a positive semiconductor that has too few electrons due to the special make-up of a different impurity, thus creating 'holes' in its lattice. At the P-N junction, where these two semiconductors meet a diode, the free electrons on one side of the junction are attracted to the holes on the other side. When the electrons settle into their new found holes, they resume their normal energy state, giving up excess energy in the form of photons. The diode glows as a result.

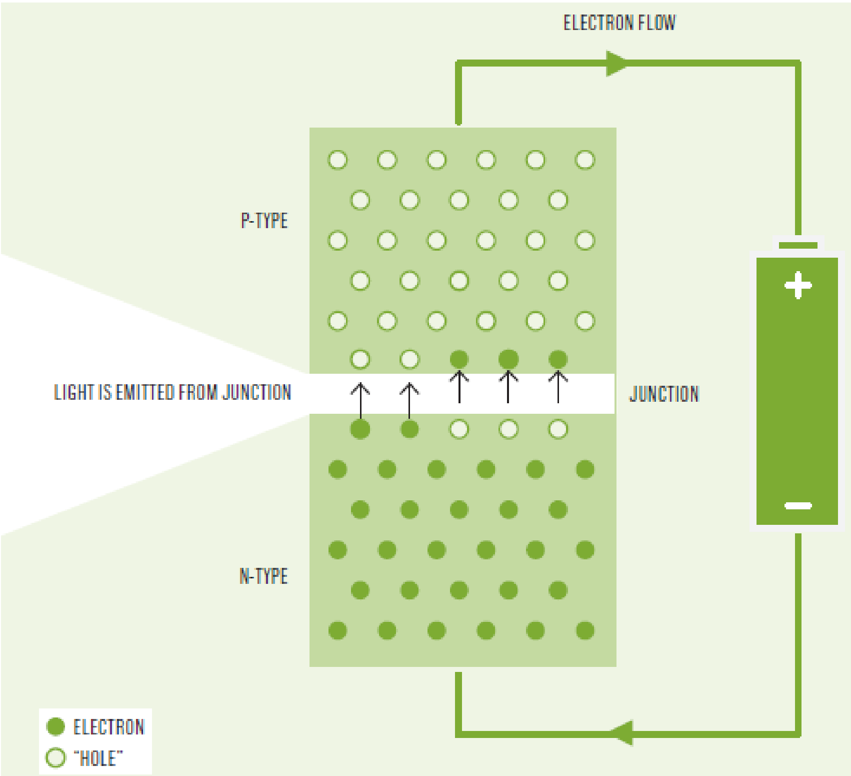


Figure 9: How LEDs produce light

White light LED technology for general illumination

To produce white light for general illumination applications in LEDs, multiple colours must be controllably mixed. White light LED components and luminaires are typically based on either of the three approaches:

(a) phosphor-conversion (b) discrete colour-mixed (c) a hybrid approach (which combines the phosphor conversion and colour mixed approaches).

[24] Annexure of 'LIGHTING THE CLEAN REVOLUTION - The rise of LEDs and what it means for cities', Philips, June 2012

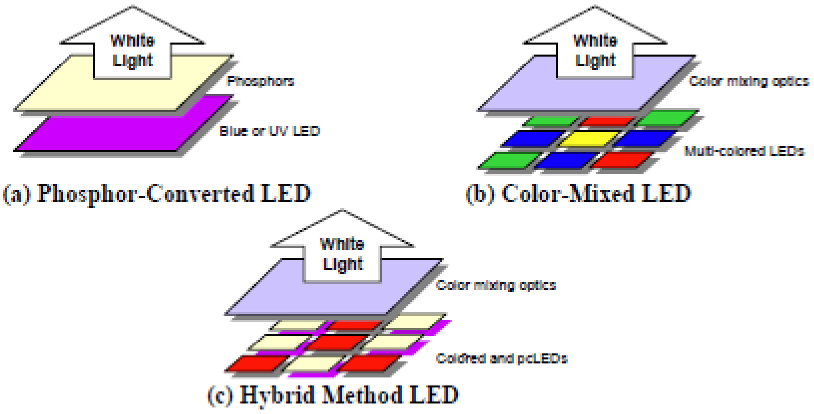


Figure 10: White light production from LEDs

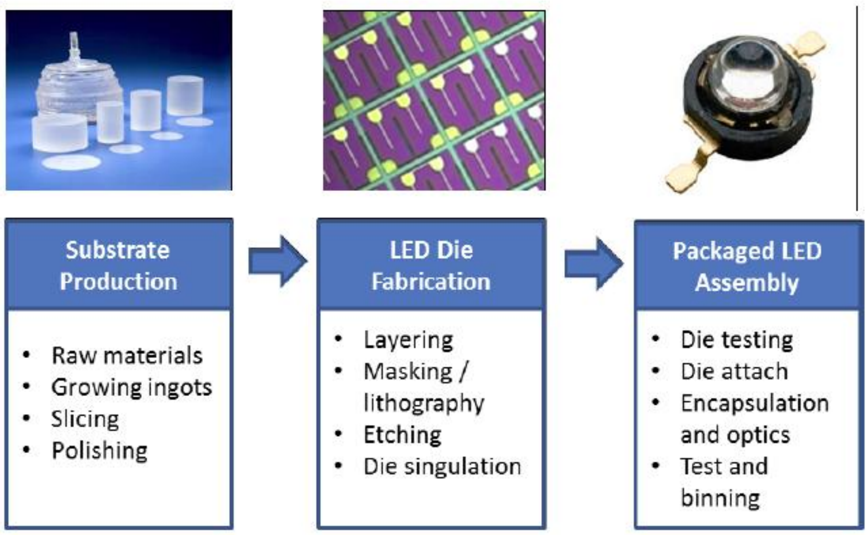
Today, most LEDs use the phosphor-converted (pc) approach for white light creation. It is generated by mixing a portion of the blue light emitted directly from a GaN LED die with down-converted yellow light emitted by a phosphor which can be located on the LED emission surface, within the encapsulant, or spaced away from the LED (remote phosphor). Many manufacturers have successfully lowered the CCT and increased the CRI by blending red emitting phosphor with yellow phosphor.

The development of 'White-light LED's' capable of producing high intensity white light have further enhanced the spectrum of their usage in room lighting, lamps, automotive lighting, etc.

The manufacturing of white light LEDs

LED manufacturing is an intricate and highly technical process. Consequently very few companies in the world operate across all segments of the value chain. To simplify the process for producing a packaged LED and to better align with the areas of specialisation and expertise that exist in the industry, the value chain for LED manufacturing can be broadly divided into three large segments. (1) substrate production, (2) LED die fabrication (3) packaged LED assembly.

Manufacturing phases of packaged white light LED assembly



Source: 'Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products, Part2: LED Manufacturing and Performance', Office of EERE, US DoE, June 2012

Substrate production

This stage is focused on preparing polished, cleaned sapphire wafers to be used in an MOCVD reactor for LED die fabrication. Wafer manufacturing starts with the growth of large sapphire crystal boules. To produce these boules, a large amount of aluminium oxide is melted down and a seed crystal is introduced to the molten solution. This seed crystal is then pulled slowly out of the solution, and because crystal growth occurs uniformly in all directions, the cross section of the resulting crystal is circular. The diameter of the crystal is a function of the melt temperature, the speed of rotation and the speed at which the seed holder is pulled from the melt. The resulting boule must then be grounded down to obtain the desired diameter before it is sliced into wafers, polished and cleaned for LED fabrication.

1. Preparation of the semi-conductor wafers

An LED is essentially a diode. Hence, the semiconductor core consisting of the *p-n* junction forms the core of the LED. The colour emitted by the LED is generally governed by the semiconductor and the doping used. There are various methods of fabricating the semiconductor to the appropriate thickness and the right doping for the particular colour. The step involves creating a wafer, polishing it and chemical cleaning to remove any impurities. The wafers are prepared for the next step.

2. Adding epitaxial layers

Here the semiconductor wafers are 'grown' in thickness. This method produces exceptionally uniform layers which are several microns thick. Additional dopants can be added for enhanced efficiency or colour. Generally nitrogen or zinc ammonium is the preferred dopants. Nitrogen makes the emitting light a higher shade of yellow or green.

LED Die fabrication process

In the epitaxial growth phase, the substrate is mounted in an metal organic chemical vapour deposition (MOCVD) reactor and experiences a heating stage, followed by the deposition of the nucleation layer, the n-type layer, the active layers (multi-quantum well) and finally the p-type layer. At the end of this phase, the wafer is referred to as an LED epitaxial wafer.

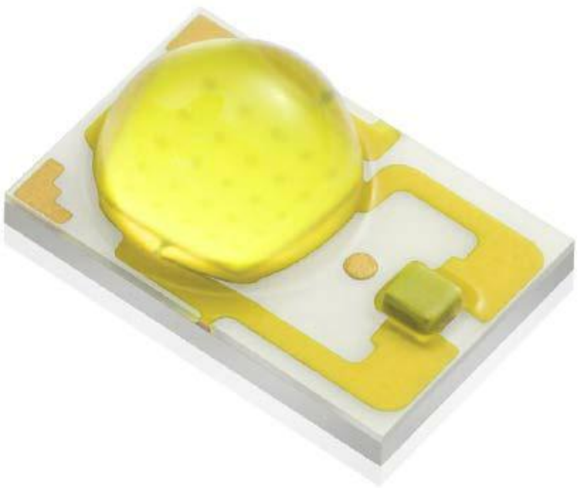
The nucleation layer is critical because crystalline or contaminate defects will have a detrimental effect on the yield from the wafer, so it is imperative that the sapphire layer is ultra-pure. This is a layer of sapphire that is grown on the raw sapphire wafer through an epitaxial growth process. The layer is quite thin, just 3% or less of the wafer thickness, but is a critical step in the fabrication process.

Taking the LED epitaxial wafer, a series of steps are followed which are working toward making the device and preparing it for packaging. Following inspection, the wafer is subjected to masking or lithography, followed by etching and then establishing metallimetallisation or contacts on the LED. These process steps create the LED mesa-structure, resulting in visible LED dies on the wafer. Once these are developed, the substrate is separated from the LED dies, and they are then cut (i.e., die singulation) and tested, binned according to their performance. At the end of this stage, the LED dies are ready to be packaged.

Packaging the LED assembly

This third phase of LED manufacturing is referred to as the packaging of the device. It involves taking the LED die, mounting it in housing, making electrical connections, applying phosphor, encapsulate and optics. It also involves testing and binning the LED into the correctly classified product

Finished Packaged LED, the Philips Luxeon Rebel: An illustration



Raw materials

The major raw materials required in the manufacture of LED's

1. Semiconductor with dopant
2. Appropriate phosphor compound

Various materials used for multi- colour LEDs

S no	Colour	Semiconductor used
1	Infrared	Gallium arseide (GaAs)
		Aluminium gallium arsenide (AlGaAs)
2	Red	Aluminium gallium arsenide (AlGaAs)
		Gallium arsenide phosphide (GaAsP)
		Aluminium gallium indium phosphide (AlGaInP)
		Gallium(III) phosphide (GaP)
3	Yellow	Gallium arsenide phosphide (GaAsP)
		Aluminium gallium indium phosphide (AlGaInP)
		Gallium(III) phosphide (GaP)
4	Green	Indium gallium nitride (InGaN)/Gallium(III) nitride (GaN)
		Gallium(III) phosphide (GaP)
		Aluminium gallium indium phosphide (AlGaInP)
		Aluminium gallium phosphide (AlGaP)
5	Blue	Zinc selenide (ZnSe)
		Indium gallium nitride (InGaN)
6	Violet	Indium gallium nitride (InGaN)
7	Purple	Dual red,blue LED's, blue with red phosphor Or white with purple plastic
8	Ultraviolet	Diamond

		Boron nitride (BN)
		Aluminium nitride (AlN)
		Aluminium gallium nitride (AlGaN)
		Aluminium gallium indium nitride (AlGaInN)
9	White	Blue,UV LED with yellow phosphor

For commercial purposes, white-light LED is used. Indium gallium nitride (InGaN) is the most widely used semiconductor in white-light emitting LED.

Cerium-doped Yttrium Aluminium Garnet (Ce^{3+}:YAG) is the most commonly used phosphor. Phosphors are substances that exhibit the phenomena of luminescence that is, emit light under typical circumstances. They include both phosphorescent and fluorescent materials. These are generally transition metal or rare earth compounds.

Key players in the manufacturing segment

LED-based SSL technology has its roots in the initial demonstration of a high performance blue emitter using GaN by Nichia in 1993. More specifically, a few years later, the same group demonstrated a white LED through combining the blue LED with an yttrium aluminium garnet phosphor. This set the scene for general lighting applications of the SSL. Subsequent to these announcements there was an explosion of R&D activity worldwide culminating in the commercial availability of white HB LEDs from Nichia (Japan), Toyoda Gosei (Japan), Philips Lumileds (US), Cree (US), and OSRAM (Europe). These companies continue to be the major players However, patent cross-licensing has opened the market to other players and has broadened the R&D base.

.**Leading manufacturers of LED chips, components and fixtures* in the world**[25]

Company	**Sales (million USD)**	**Country**	**Type**
Toyoda Gosei	6612	Japan	LED Chips
OSRAM opto semiconductors	621.2	Germany	
Veeco	403	USA	
Epistar corporation	310.7	Taiwan	
CREE	394.1	USA	
Seoul semiconductors	284.2	South Korea	
Philips Lumileds	75	Netherlands	
Seikoh Giken	62.5	Japan	
Toyoda Gosei	5796	Japan	LED components
Everlight Electronics	309	Taiwan	
OSRAM opto semiconductors	621.2	Germany	
CREE	394.1	USA	
Dow Cowning corporation	2205	USA	
Supertex	83	USA	
Power Integrations	191	USA	
Edison Opto Corporations	16.8	Taiwan	
Philips Lumileds	75	Netherlands	

[25] Lighting industry: Structure and Technology in the Transition to Solid State" Susan Sanderson et al

Rubicon Technology	34.1	USA	
GE Lumination	15	USA	
CAO group	38	USA	
Gentex	653	USA	
CREE	394.1	USA	
American Opto Plus LED	450	USA	LED lighting products and fixtures
Teledyne Technologies Inc	1622.3	USA	
Philips Lumileds	75	Netherlands	
LEDtronics	40	USA	

*This list is not a complete and exhaustive list as there are many other players in the un-organised segment

Majority of the manufacturers belong to the US, Japan, Taiwan or Europe (Netherlands, Germany). The actual LED manufacturing process is a very complex one requiring various processes and varying compositions of the raw materials.

Components of LED luminaires[26]

LED: It refers to a p-n junction semiconductor device (also referred to as chip) that emits incoherent UV, visible, or infrared radiation when forward biased

LED package: It refers to an assembly of one or more LEDs including wire bond or other types of electrical connections (thermal, mechanical, or electrical interfaces) and optionally an optical element.

Power source and standardised base are not incorporated in the device. The device cannot be connected directly to the branch circuit.

LED array or module: It is an assembly of LED packages (components), dies on a printed circuit board or substrate, possibly with optical elements and additional thermal, mechanical, and electrical interfaces that are intended for connecting to the load side of a LED driver. Power source and standard base are not incorporated into the device. It cannot be connected directly to the branch circuit.

Subassemblies and systems

LED driver: It is a device comprising a power source and LED control circuitry designed to receive input from the branch circuit and operate a LED package (component) or an LED array (module).

- Power supply: It_refers to an electronic device capable of providing and controlling current, voltage, or power within design limits. An LED light works on a DC current. The supply to domestic and commercial sectors is usually AC current of 230V. The voltage driver is essentially a step down transformer come rectifier, which steps down the voltage from 230V to the desired level and converts the AC to DC.

- LED control circuitry: It refers to electronic components designed to control a power source by adjusting output voltage, current or duty cycle to switch or otherwise control the amount and characteristics of the electrical energy delivered to a LED package (component) or an LED array (module). LED control circuitry does not include a power source.

The LED light engine_consists of an integrated assembly comprised of LED packages (components) or LED arrays (modules), LED driver, and other optical, thermal, mechanical and electrical components. The device is intended to connect directly to the branch circuit through a custom connector compatible with the LED luminaire for which it was designed and does not use a standard base.

[26] Illumination Engineering Society of North America; Solid state lighting R&D, Multi Year program plan, US DoE, March, 2011

Heat sink: Unlike other technology LED luminaires dissipates a lot of heat in the form of convection and conduction. Thermal management of LED lighting is critical for maintaining the lumen output during its life. As the number of LED's in an LED light increases, or when the lumen output of the light increases, heat dissipation becomes a major issue.

LED lamp: It refers to an assembly with a standardised base designed for connection to an LED luminaire. There are two general categories of LED lamps:

- An integrated LED lamp refers to an integrated assembly comprised of LED packages (components) or LED arrays (modules), LED driver, heat sink, standard base and other optical, thermal, mechanical and electrical components. The device is intended to connect directly to the branch circuit through a corresponding standard lamp-holder (socket).

- Non-integrated LED lamp refers to an assembly comprised of an LED array (module) or LED packages (components) and standard base. The device is intended to connect to the LED driver of an LED luminaire through a standard lamp-holder (socket). The device cannot be connected directly to the branch circuit.

Figure 11: Components of LED luminaire

LED luminaire_refers to a complete lighting unit consisting of LED packed assembly and a matched driver together with a heat sink and other optical elements to distribute light, position and protect the light emitting elements, and for connecting the unit to a branch circuit. The LED luminaire is intended to connect directly to a branch circuit with the help of a customised fixture.

LED luminaire products in India for general lighting

The Mckinsey's 2012 Global Lighting Market Model predicted that the overall luminaire market in India (including retrofit lamps) would be about 11,000 crore INR in 2012. The same model also suggested that the share of LED luminaires in the overall market will be about 9% in 2012, translating into 990 crore INR.

At present, more than 70% of the components of LED lighting are imported in India. The major components imported are LED package assembly, arrays, modules, drivers and MCPCBs.

There are about 200 players in the country in the LED lighting market.

- MNCs like Phillips, OSRAM and GE
- Major lighting players like Bajaj and Wipro
- MIC with sole focus on LED displays and lighting products

- Several other companies engaged in the design, development and manufacture like Sanarthi Incorporated, Reiz Electronics, Surya, CGL, Kripa Telecom, Avni Energy, Goldwyn and Greenolite, etc.

Many large-scale, established manufacturers (Philips, Osram and GE Lighting) have started indigenous production of LED drivers and MCPCBs suitable to Indian conditions. The technology of LED packaging (production of LED chips, arrays, modules) is still rapidly evolving globally and is in its nascent stage. Indigenisation of this technology may take several years requiring aggressive R&D within the country supported by government funding. Importing this technology and indigenous production by established players may take around five to 10 years. It needs an appropriate policy framework, incentives and government support. Since technology transfer is valued as expensive, most of the medium and small scale LED luminaire suppliers in the country assemble the necessary imported components in various configurations and further sell the products through organised and unorganised channels.

The LED lumainaire market in India can be broadly divided into two major segments.

LED professional products (Luminaires)

The professional products cater mostly to the upcoming floor space or the new construction segment. These products comprise of various designs of fixtures for a wide variety of applications. Aesthetic appeal is a key characteristic for these products when promoted to the builders. This sometimes may compromise the potential energy savings due to the reduced application efficiency. However professional products when integrated with smart controls provide enhanced opportunity of energy savings.

Professional LED products by GE Lighting India; LED Fern and Cove lighting systems for office and building illumination: An illustration

LED replacement and retrofit Lamps

LED replacement lamps are customized retrofit solutions, which replace the conventional lamps, for general lighting in the Indian residential and commercial sectors. Replacing the existing fixtures that already hold the conventional lamps is not required for retrofit solutions. The standard LED replacement tubes can be installed in the existing T12 or T8 fixtures after disconnecting the starter and the choke electronics. The standard LED replacement bulbs come with both, a screw base and two pin-bases. It can be installed in the standardised incandescent CFL holders.

LED replacement, retrofit lamps by Osram (LED Parathom & SubstiTUBEs) and Philips (Master LED lamps) for the Indian market: An illustration

The promise of LEDs

LEDs have the potential to bring a lighting revolution and are evolving much faster than any other established incumbent lighting technology in the market. The white LED efficiency has increased by a factor of ten in the last decade. Today, LEDs are among the most efficient lighting sources available, but in the near future they will reach far beyond any competing technology and become the technology of choice for most applications; with energy savings reaching up to 90% compared to the prevailing conventional technologies.

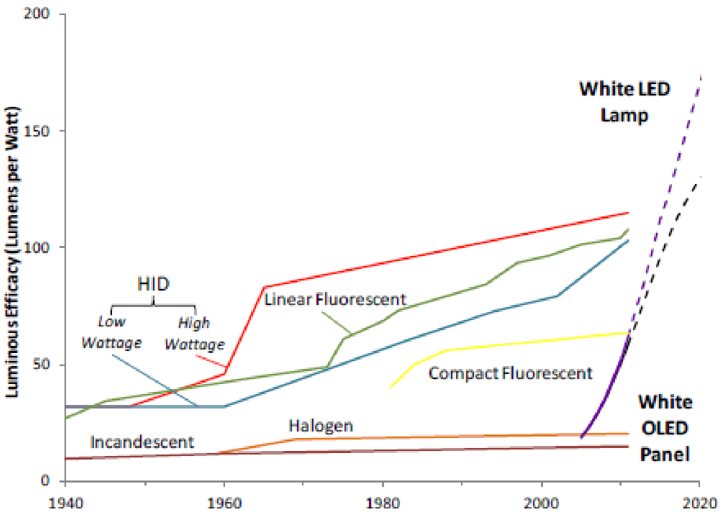
LEDs primarily offer advances in efficiency, controllability and directionality, and life span.

White light LED efficiency

LEDs are exceptionally high on theoretical energy efficiency and intensive research is rapidly unlocking this potential. The maximum achievable theoretical efficiency of colour mixed LEDs is 266 lm, watt whereas for phosphor converted LEDs is 199 lm, watt. Already, LED efficiency is fast surpassing that of conventional lighting technologies. Today phosphor-converted LEDs have demonstrated efficacies of up to 144 lm,watt for cool white emitters and 111 lm,watt for warm white emitters. The luminaire efficiency of LED that incorporates other electrical, mechanical and thermal losses is around 65 lm,watt, surpassing the incandescent, halogen and CFL counter parts, but marginally lower than some of the high efficient linear fluorescent ones.

The luminaire efficacy is a key metric for assessing the efficiency. It is the ratio of lumen output to the electrical power applied to the luminaire. The LED package efficacy (or the luminous efficacy) refers to the ratio of lumens out of the LED package to the power applied at room temperature, thus not including the driver, luminaire optical or thermal losses. It is important to keep in mind that it is the luminaire's performance that ultimately determines the actual energy savings.

Evolution of various lighting technologies



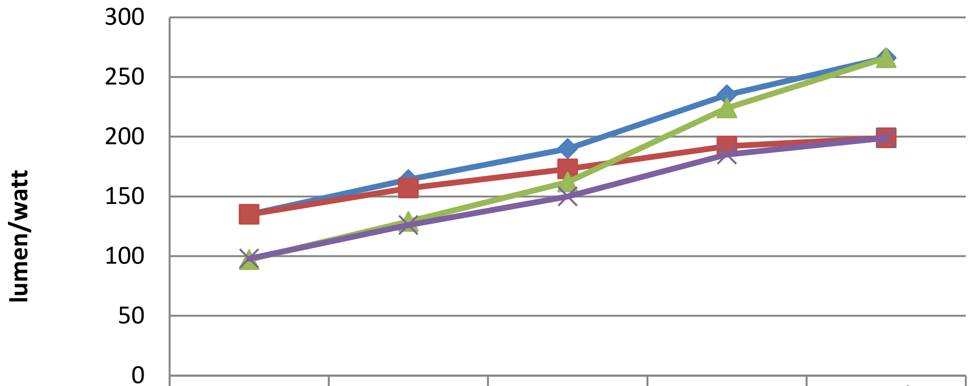
Source: Solid state lighting R&D, Multi Year program plan, US DoE, March, 2011

The current incandescent and halogen light sources typically range in efficacy from 10 to 20 lm per watt. Efficacies for fluorescent lamps range from 25 to 118 lm, watt, depending on the length, wattage, and colour temperature. However, this efficacy does not account for ballast losses. Their inclusion results in overall fluorescent system efficacies as high as 108 lm per watt.

The EERE (Energy Efficiency and Renewable Energy), US DoE has set multi year programme goals for (MYPP) its solid state lighting (SSL) based R&D programme. The 2012 updated document has set targets and projections for LED package efficacy, LED luminaire efficacy, and improvements in driver, thermal and fixture efficiency for the years 2013, 2015 and 2020. These targets and projections are based on inputs gathered from R&D workshops and roundtable attendees.

For phosphor converted products, one can see that the LED package efficacies have reached 135 lm per watt and 98 lm per watt for cool white and warm white packages respectively. The Figure 12 also shows the respective goals for package efficacy, which represents the 'reasonably' achievable efficacies for practical devices. A starting point in estimating this is the theoretical maximum efficacies of an SSL product given the perfect conversion of electricity to light. This 'ideal' performance is characterised by the luminous efficacy of radiation (LER), which is the useful light in lumens obtained from a given spectrum per watt.

Figure 12: LED package efficacy projections



	2011	2013	2015	2020	Goal
Cool White (Color-mixed)	135	164	190	235	266
Cool White (Phosphor)	135	157	173	192	199
Warm White (Color- mixed)	97	129	162	224	266
Warm White (Phosphor)	98	126	150	185	199

Source: Solid state lighting R&D, Multi Year programme plan, US DoE, April, 2012

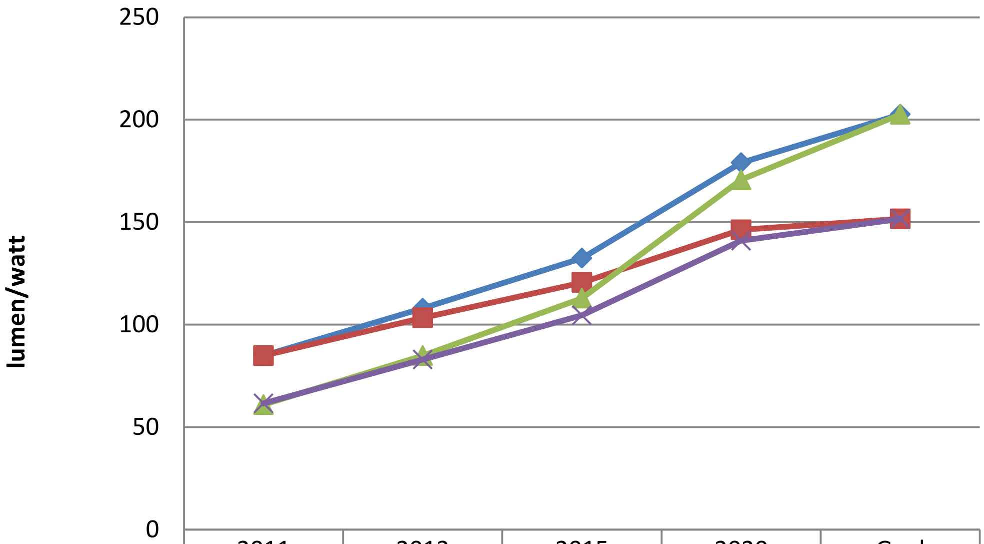
As mentioned earlier, in order to assess the actual energy savings resulting from the light source, it is important to understand the efficiencies of subassembly and other systems (driver, heat sink, fixture and other optical and electrical components) in the LED luminaire. The 2012 MYPP for SSL programme of the US DoE has allocated these efficiencies for 2011 and further set targets for the future. One can observe that the resultant luminaire efficiency is 63% currently and this is expected to increase to 92% by 2020 due to advances in driver technology and thermal management.

Table 19: LED sub-assembly efficiency projections

Efficiency projections of LED subassembly and other systems					
Year	**2011**	**2013**	**2015**	**2020**	**Goal**
Thermal efficiency	86%	87%	88%	90%	90%
Efficiency of driver	85%	87%	89%	92%	92%
Efficiency of fixture	86%	87%	89%	92%	92%
Resultant luminaire efficiency	63%	66%	70%	76%	76%

The figure shows luminaire efficacy values estimated by multiplying the overall efficiency with the LED package efficacy for various LED light sources. These values represent the overall system efficacy targets for LED luminaires and define the performance that ultimately determines actual energy savings. For phosphor converted LED products, one can see that the 2012 MYPP for SSL programme of US DoE has allocated luminaire efficacy of 85 lm, watt for cool white and 62 lm, watt for warm white packages. Since the products vary across the globe, these may be a perfect representation for products available in the US markets, but not for the Indian market. The later sections attempt to understand this gap based on our own analysis of the LED replacement products available in the Indian market.

Figure 13: LED luminaire efficacy projections



	2011	2013	2015	2020	Goal
Cool White (Color-mixed)	85	108	132	179	203
Cool White (Phosphor)	85	103	121	146	152
Warm White (Color- mixed)	61	85	113	171	203
Warm White (Phosphor)	62	83	105	141	152

Source: Solid state lighting R&D, Multi year programme plan, US DoE, April, 2012

Controllability and directionality

Conventional lighting technologies tend to suffer decay in quality over time (known as lumen depreciation) and have shorter useful lives when they are dimmed. Yet the lifespan of an LED product actually increases when the average current flowing through it is reduced. This makes it better suited to smart controls than any previous lighting technology, further increasing the potential for energy efficiency and making it possible to match light output closely to need.

LEDs provide highly directional light, meaning that they shine light only where it is needed. This accounts for a large proportion of the technology's energy-saving potential. In the case of street lighting this can reduce light pollution by preventing light from intruding into residential windows or the night sky.

Long life-span

The materials used in making the LEDs are inherently stable. Laboratory testing, and experience with the stability of the silicon carbide from which many semiconductors are made, indicates well-produced LEDs may last from 50,000 to 100,000 hours and beyond. This is two to five times longer than the most advanced fluorescent lamps. Most of the LED replacement products available today have minimum 25000 hrs of rated life. Such products can replace three CFLs (with lifetime of 8000 hours) and 25 incandescent lamps (with lifetime of1000 hours) during the entire life-time of the usage. For some high performance cool white products the rated life is between 40,000 to 50,000 hours.

First cost of LED lighting

The prices of light sources are typically compared on a price per kilolumen basis. On a normalised light output basis (dollars per kilolumen), in 2011, LED lamps remain around twelve times the cost of the halogen bulb and around three times the cost of an equivalent dimmable CFL. The first costs for principal LED replacement lamps have dropped considerably in the last five years but the challenge facing SSL in the market-place remains today. However, industry experts believe that the price of LED lamps is expected to continue its rapid decline and the performance is expected to continually improve. As a consequence, LED light sources are projected to become increasingly competitive on a first cost basis.

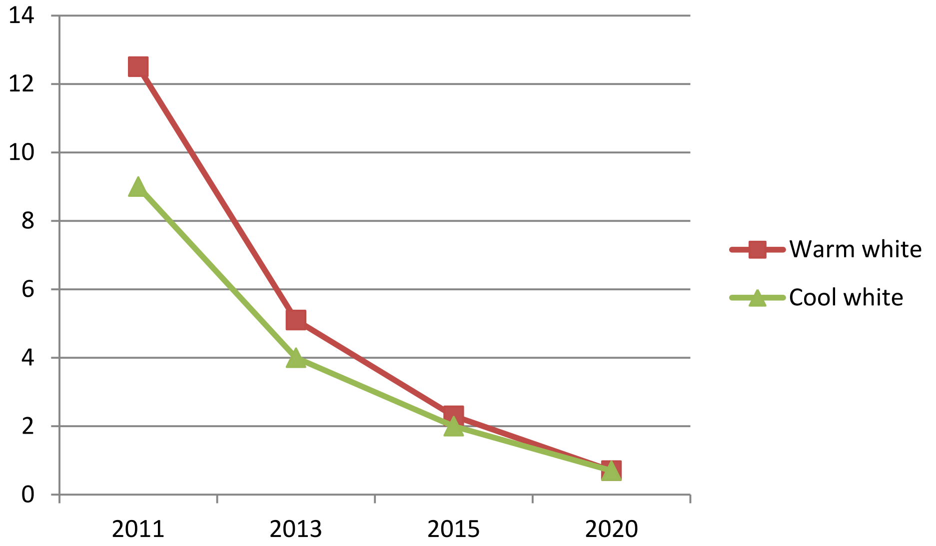
First cost of light sources in 2011

Lamp type	First cost	Unit
Halogen Lamp (A19 43W; 750 lumens)	$2.5	per kilolumen
CFL (13W; 800 lumens)	$2	per kilolumen
CFL (13W; 800 lumens dimmable)	$10	per kilolumen
Fluorescent Lamp and Ballast System (F32T8)	$4	per kilolumen
LED Lamp (A19 60W; 800 lumens dimmable)	$30	per kilolumen
OLED Luminaire	$1,700	per kilolumen

Source: Solid state lighting R&D, Multi Year program plan, US DoE, April, 2012

The white light LED package, which consists of the LED chip, is the heart of the lamp and also contributes about 30 to40% of the overall price. The price of the LED package drives the overall luminiare price and each LED manufacturer produces a number of variants for each package design covering a range of colour temperatures and lumen output. As per the US DoE, the white LED packages have seen a modest overall price reduction, with the price of warm white packages at 12 USD per klm and cool white LED packages at 8USD per klm in 2011. These price estimates have been derived from typical retail prices for LED packages purchased in quantities of 1,000 from major commercial distributors in the US such as Digi-Key, AVNET, Newport, and Future Electronics. One can observe that the prices of LED packages may fall beyond 2 USD by end of 2015 and further fall below1USD by 2020.

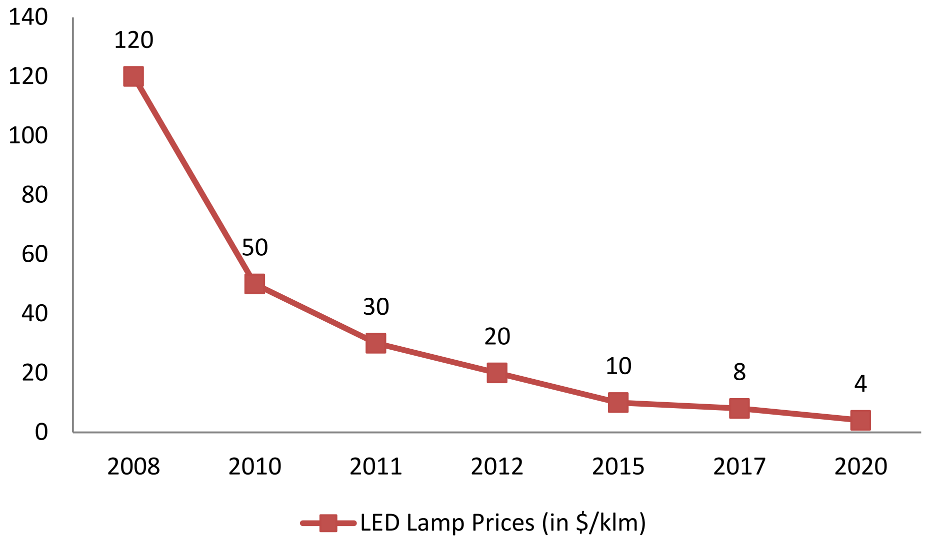
Figure 14: White light LED package prices (in USD, klm)



Source: Solid state lighting R&D, Multi year programme plan, US DoE, April, 2012

The rapid fall of LED lamp prices in the last five years and also the expected fall in prices in the next decade is depicted. By the end of 2012 the prices are expected to come down to 20 USD per klm and by the end of the 12th Five Year Plan, the LED lamp prices may be less than 10 USD per klm thus achieving parity with the dimmable CFL lamps in the current pricing scenario. By the end of this decade the prices are expected fall below 5 USD per klm.

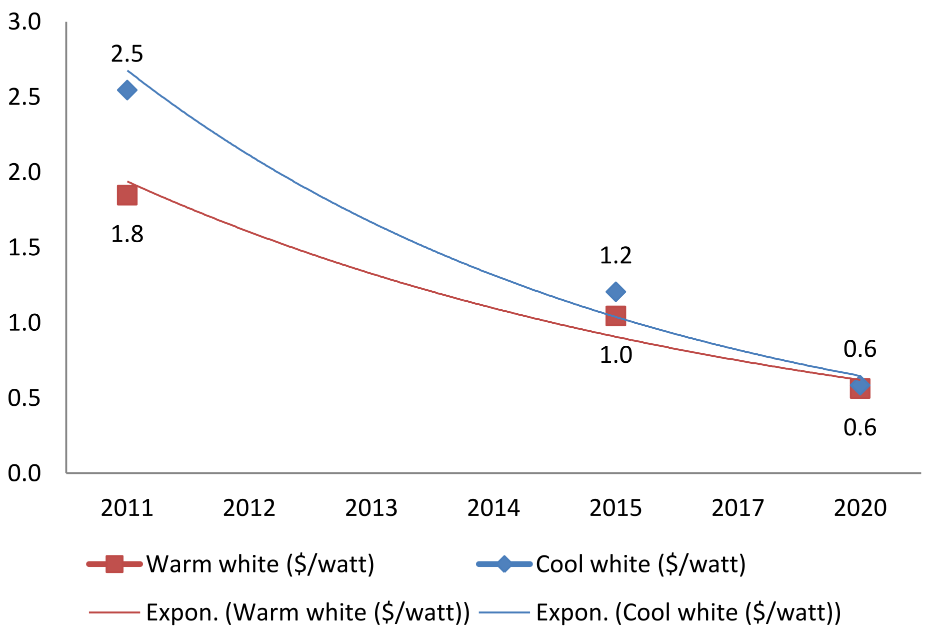
First cost trend of the LED lamps (USD per kilolumens)



Source: Solid state lighting R&D, Multi year programme plan, US DoE, April, 2012

An interesting analysis further will be to deduce the LED replacement lamp prices in terms of price per wattage taking the impact of overall efficacy improvements also into consideration. In order to do this, the first costs per kilolumens presented here have been multiplied by the LED luminaire efficacy projections (with an adjustment factor of 1/1000) of the US DoE discussed earlier. This analysis shows that the current prices of LED lamps are between 1.5USD to 2.5 USD per watt and the same is expected to fall below 1USD beyond 2015. This pricing scenario is based on studies pertaining to the US markets and therefore cannot be expected to be the same globally. However the price reduction trend may be expected to be the same globally with some time lag in the developing countries. The Indian scenario is discussed in the later sections.

Figure 15: LED lamp prices in USD$ per watt



Source: PwC analysis

Economies of scale and LED luminarie prices

The advantages of economies of scale in procuring LED lamps have been discussed with the manufacturing industry and as per consultations. The prices of LED luminaires is primarily driven by its package prices, which in turn depends on raw material prices for manufacturing LED packages, fixed and variable costs of production. The other subcomponents (balance of system) of LED luminaires also drive LED luminaire prices and the indigenous production of these sub components has already started in India. The raw materials industry, especially the semi conductor and other rare earths, have no effect on the demand for LED lighting as the industry is driven by various other electronic equipment market. Therefore the major advantage derived from the economies of scale can be the enhanced production efficiency, thus reducing the production costs marginally, between 5- to 10%, as per the information shared by some of the key players in the manufacturing industry. However the recent transactions involving production and sale of high volumes of LED lamps have shown drastic reduction in prices by 50 to 60%.

Market reconnaissance of LED lamp characteristics in India

In this section, the team has analysed the performance characteristics and pricing of LED replacement lamps (bulbs and linear tubes) available in the Indian market. The objective is to benchmark the current luminaire efficacy and first cost of the lamps in Indian markets, to forecast the future trend of these parameters. As discussed before there are very few established LED retrofit lamp suppliers in the country, but there are many medium and small scale suppliers providing LED retrofit solutions through organised and unorganised channels.

The team has reviewed the product catalogues of potential suppliers and manufacturers exhibiting their products in ELCOMA organised LED lighting exhibitions in 2012. Subsequently they also held consultations with the LED lighting manufacturers in India to understand and verify the current status and future trends.

The current luminaire efficacy for warm white LED replacement bulbs available in India is about 70 lm, watt whereas for cool white LED replacement tubes is about 75 lm, watt. The projections of US DoE's SSL R&D programmes has indicated about 14% CAGR in the efficacy improvement for warm white sources and about 7% for the cool white sources. The same growth rates are used to forecast improvements in the Indian market. As per the product catalogues the first cost of warm white LED replacement bulbs available in India is about 100 INR per watt whereas the cost of cool white LED replacement tubes is about 150 INR per watt. The reduction in these costs is distributed uniformly for the next decade, between the current levels and US DoE's target pricing for 2020.

One can observe that the LED replacement products may achieve 100 lm, watt efficacies by 2016 and the same could reach up to 140 lm, watt by 2021, which is almost double the current level. This improvement is still significantly lower than what the US DoE has predicted for 2020. However the impact in terms of wattage reduction is also estimated. The equivalent wattage of LED retrofit product for 15 watt CFL,60 watt incandescent could reduce to 5 watt from the current average of 9 watt. Similarly wattages of other LED products could also decrease providing substantial savings in the future.

Table 20: Trend for LED retrofit lamp characteristics in India

Characteristics of LED retrofit lamp solutions										
LED retrofit lamp system efficacy projections (lumen,watt)										
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Warm white LED bulbs	60	70	80	90	100	110	120	130	140	140
Cool white LED tubes	70	75	85	95	100	110	120	130	140	140
Wattages of LED retrofit lamps										

Equivalent to 15 watt CFL	11	9	8	7	6	6	5	5	5	5
Equivalent to 52 watt T12 (4 foot)	27	23	20	18	16	15	14	13	12	12
Equivalent to 28 watt T12 (2 foot)	15	13	11	10	9	8	7	7	6	6
Equivalent to 38 watt T8	27	23	20	18	16	15	13	12	11	11
Equivalent to 60 watt incandescent	11	9	8	7	6	6	5	5	5	5
Equivalent to 30 watt T5	23	21	19	17	16	14	13	12	11	11
Initial cost of LED retrofit lamps (in INR per watt)										
LED retrofit bulb	100	90	80	70	60	50	40	30	20	20
LED retrofit tubes	150	135	120	105	90	75	50	40	30	30
Life of LED retrofit lamps (in hours)										
LED retrofit bulb	25000	30000	35000	40000	45000	50000	60000	70000	80000	90000
LED retrofit tubes	35000	40000	45000	50000	55000	60000	70000	80000	90000	100000

Source: PwC Analysis

These projections form the basis for assessing the financial feasibility of LED demand aggregation options.

Energy savings and GHG reduction potential from LED based general lighting solutions

The objective of this task is to estimate the total energy savings and GHG reductions potential that can result from the complete market penetration of LED based general lighting solutions in the residential and commercial building categories in India.

The energy savings potential in the present scenario is estimated using the following formula.

$$Energy\ Savings\ Potential = \sum_{Conventional\ technologies} \frac{Share\ of\ lighting\ market\ (tlm - hrs)}{Efficacy\ (lm/watt)} - \frac{Total\ lighting\ Demand\ in\ (tlm - hrs)}{Efficacy\ (lm/watt) of\ LED}$$

In India, thermal power is the mainstay of electricity generation. In CO2, Baseline Database for the Indian power sector published by the Central Electricity Authority, for every MWh of energy generated in India about 0.85 tCO_2 (or equivalent) was emitted during 2009-10. This statistic has remained constant over a period of time. The same has been used to estimate GHG reduction potential.

The annual energy savings and GHG reductions potential from the complete market penetration of LED based general lighting solutions are to the tune of 28,553 GWh and 24.3 million tCO2 respectively. The energy savings potential and GHG reductions estimated above are the overall national level estimates of the lighting market in the residential and commercial building categories.

Energy savings potential and GHG emission reductions in 2011

Sector	Energy saving potential in giga watt hours	GHG emission reductions in million tCO2
Residential buildings	22390	19
Commercial buildings	6163	5.2

The residential buildings contribute 75% of the national savings potential where as the commercial sector is contributing for the remaining 25% potential.

Avoided generation capacity

This section estimates the avoided generation capacity (MW) resulting from the complete market transformation of general lighting products (in residential and commercial buildings) into LED based lighting solutions. The avoided capacity (MW) is calculated in terms of 'peak avoided load' using the formula mentioned below.

$$\textbf{Avoided capacity at the generation end, MW} = \frac{\{(CLC - CLed)\} \times PCF}{PLF \times (1 - T\&D)}$$

- CLC = Total connected load of conventional lighting products
- CLed = Total connected load of equivalent LED lighting products
- PLF = Plant load factor = 78%
- T &D = Transmission and distribution Loss = 20%
- PCF= Peak coincidence factor = 0.7

The potential for avoided generation capacity (MW) from the complete market penetration of general lighting products is to the tune of 20 GW_p in residential buildings and 4.7 GW_p in commercial buildings. The avoided capacity potential estimated above is the present overall national level estimate of the lighting market in the residential and commercial building categories.

Life cycle costing assessment for various general lighting technologies

The life cycle cost of general lighting lamps can be a useful parameter to assess the overall cost of lamp operation during its lifetime. The lamp wattage, rated life, first cost and replacement cost are the major parameters driving the overall life-cycle cost of a lamp during its operations The assessment shows that the life cycle cost of LED bulb is only 25% of the incandescent lamp and slightly lesser than the CFL in the current scenario. The life cycle cost of LED replacement tube is currently 70% of the T12 tube only slightly lesser than the T8 tube. Clearly the T tubes are more efficient than the LED ones. This shows that LED replacement products for T8 and T5 fluorescent tube lamps have a long way to go to prove their efficiency and cost effectiveness. Similarly LED bulbs also can improve substantially to reduce the life cycle costs in the future to compete with the CFL counterparts.

Table 21: Life cycle cost assessment

Technology	Average lamp system efficacy (in lumens per watt)	Wattage to match desired lumens	Rated life (in hours)	Energy use over lamp operational life (in kWh)	Initial cost (INR)	Replacement cost (INR)	Number of lamps to match LED life	Overall life cycle cost (INR)
ICL	15	60	2000	120	15	15	13	7995
CFL	60	15	6000	90	150	150	4	2400
LED bulb	70	9	25000	225	900	900	1	2025
T12	45	52	5000	260	150	52	8	10914
T8	60	38	8000	304	300	70	5	8180
T5	75	30	10000	300	500	120	4	6860
LED	75	22	40000	880	3300	3300	1	7700

Modelling market penetration of LED based general lighting solutions

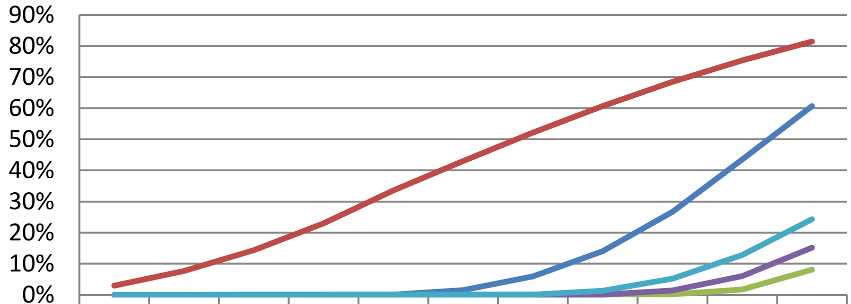
This assessment attempts to use an empirical model to estimate the penetration of LED based general lighting solutions in the Indian markets. This was prepared by Arthur D. Little Inc for the Department of Energy, US government, used simple payback period as the primary driver influencing lamp purchase decisions by end users.

The Arthur D. Little model uses the following simple payback period formula

$$\text{Simple Payback (yr)} = \frac{-\Delta Purchase\ Cost\ (INR/klm)}{\Delta Annual\ Electricity\ Cost\ (INR/klm/yr)\ +\ \Delta Annual\ Lamp\ ReplacementCost\ (INR/klm/yr)}$$

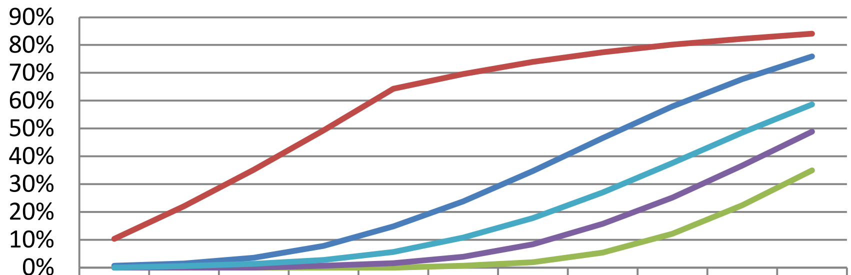
Using the above mentioned formula, this report has estimated the trend of simple payback periods for replacing conventional technologies in the next decade. The trend of LED technology characteristics presented in the earlier sections has been integrated into this model to develop the simple payback curves against each of the conventional technologies. Due to rapid technology and price improvements in the LED, the payback period against certain lighting technology are declining at a rapid pace. This may result in rapid market penetration in markets of certain lighting technologies (refer to Figure 16 and Figure 17). There are many intrinsic barriers to this rapid market takeover like demand supply gap and supply-chain failure. To overcome such aggressive scenarios, the model assumes a certain lag time for penetration.

Figure 16: LED market penetration (residential)



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CFL	0%	0%	0%	0%	0%	2%	6%	14%	27%	43%	61%
ICL	3%	8%	14%	23%	34%	43%	52%	61%	68%	75%	81%
T5	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	8%
T8	0%	0%	0%	0%	0%	0%	0%	0%	1%	6%	15%
T12	0%	0%	0%	0%	0%	0%	0%	1%	5%	13%	24%

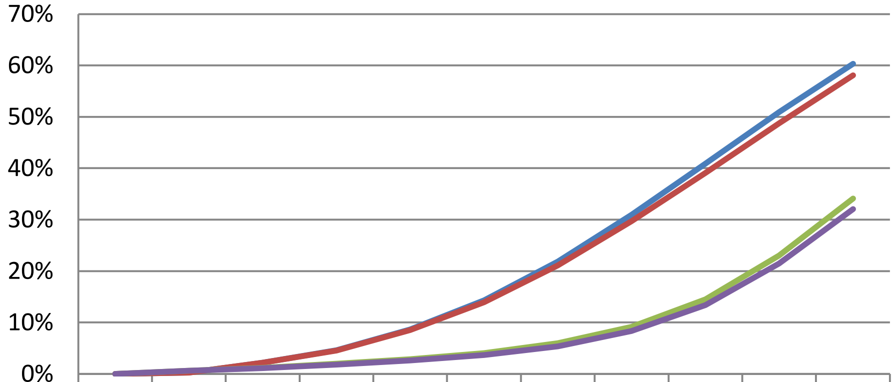
Figure 17: LED market penetration (commercial)



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CFL	1%	1%	3%	8%	15%	24%	35%	47%	58%	68%	76%
ICL	10%	22%	35%	49%	64%	70%	74%	77%	80%	82%	84%
T5	0%	0%	0%	0%	0%	1%	2%	5%	12%	22%	35%
T8	0%	0%	0%	1%	2%	4%	8%	16%	25%	37%	49%
T12	0%	1%	1%	3%	6%	11%	18%	27%	38%	49%	59%

The Figure 17 provides a tentative market share of LED replacement lamps during the next decade. One can see that the LED lighting under the expected technology improvement scenarios can occupy only 60% of the commercial lighting market and 33% of the residential lighting market by 2021.

Figure 18: Market share of LED lighting in the next decade



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Comm. Scenario 1	0%	0%	2%	5%	9%	14%	22%	31%	41%	51%	60%
Comm. Scenario 2	0%	0%	2%	5%	9%	14%	21%	30%	39%	49%	58%
Resi. Scenario 1	0%	1%	1%	2%	3%	4%	6%	9%	14%	23%	34%
Resi. Scenario 2	0%	1%	1%	2%	3%	4%	5%	8%	13%	21%	32%

Demand aggregation in BPL households

Introduction to the RGGVY scheme[27]

The government, in April 2005, launched the Rajiv Gandhi Gramin Vidyutikaran Yojana (RGGVY), a comprehensive scheme of rural electricity infrastructure and household electrification for providing electricity to all rural households. There is a provision of 90% capital subsidy of the total project cost and balance 10% of the project cost being provided by REC as loan, under the scheme. The Rural Electrification Corporation Limited (REC) is the nodal agency for implementation of the scheme in the entire country. Equal emphasis has also been accorded to sustainable rural power supply through deployment of rural franchisees and provisions for revenue subsidies from the state government as required under the Electricity Act, 2003 so as to facilitate arriving at revenue sustainable rural power supply arrangement.

Under the scheme, projects have been financed with capital subsidy for the provision of the following:

1. Rural electricity distribution backbone (REDB): Providing 33/11 KV (or 66/11 KV) substations of adequate capacity and lines in blocks where these do not exist.

2. Creation of village electrification infrastructure (VEI): Providing distribution transformers of appropriate capacity in electrified villages and habitations.

3. Decentralised distributed generation (DDG) and supply: Decentralised generation-cum distribution from conventional, renewable or non-conventional sources such as biomass, biofuel, bio gas, mini-hydro, geo-thermal, solar etc for villages where grid connectivity is either not feasible or not cost-effective provided it is not covered under the programme of Ministry of New and Renewable Energy.

4. *Electrification of BPL households: - Free electricity connection to un-electrified BPL households as per the Kutir Jyoti Programe in all rural habitations. Households above poverty line will be paying for their connections at prescribed connection charges and no subsidy will be available for this purpose.* The rate of reimbursement for providing free connections to BPL households 1500 INR per household, which was revised to 2200 INR per household during the 11th Planperiod.

The implementing agencies can be any of the following institutions:

- CPSUs
- Power departments of state governments
- State electricity boards
- Discoms and
- Co-operative societies

The government of India, in 2010, has recognised BPL household electrification under RGGVY as a key demand aggregation platform for LED replacement lamps in BPL households. In the 11th Plan, BPL households have been provided with a CFL, free of cost, along with free electricity connection under the RGGVY. In the 12th Plan, it is proposed to provide a LED lamp to BPL households instead of CFL.

[27] Report of The Working Group on Power for XII Plan (2012-17), MoP, January, 2012

Current status and 12th Plan targets for BPL household electrification under the RGGVY[28]

During the 10th and the 11th Plan periods, about three crore BPL households are electrified under RGGVY (2.4 crore) and erstwhile Kutir - Jyoti schemes (0.6 crore). The 12th Plan working committee report on power by the MoP, in 2012, has recommended a provision for providing free LED lamps to each of these three crore households during the 12th Plan. Apart from this, the working committee has also estimated another 1.14 crore BPL households to be electrified during the 12th Plan for which the same provision has been made.

The Ministry of Power initiative for electrification of villages within a 5 km radius of the central power generating stations

Under this scheme, all revenue villages and habitations, irrespective of their population, within a 5 km radius from the CPSUs power houses shall be eligible for electrification. In case a village or a habitation falls partially inside the 5 km radius, it shall also be fully covered under the scheme. At least one 11 kV radial feeder, if it does not already exist, will be provided by the CPSU for the area from the nearest existing substation of the state utility. Single phase transformers of adequate capacity, with down loadable meters, AMRs, shall be provided to villages or habitations for supplying electricity to the households and public places. The capacity of the transformers shall be sufficient to cater to the present load of all the households and public places and to meet the expected growth for five years. The meters will have the facility to record timings and duration of power supply through the transformers.

The CPSUs will also provide free single lamp electricity connections to BPL households. LED bulbs shall be provided with connections to BPL households. Supply of LED bulbs by CPSUs will be a one time affair.

Implementation methodology

- A tripartite agreement will be signed by the respective state government, the state utility and the concerned CPSU for implementing the scheme.

- The state utility will prepare a list of villages and habitations for the area falling within a 5 km radius from the CPSUs power houses. An assessment of the electricity requirement for households will be made by them. The list of villages and habitations, power requirement, etc shall then be handed over to the CPSU.

- The existing infrastructure in the identified area shall be GIS mapped by the CPSU and required modifications for implementing the scheme will be identified and marked on the maps, drawings. A detailed project report (DPR) will then be finalised by the CPSU in association with the state utility and approved by the state government. A list of BPL households shall be supplied by the state utility or the district administration for providing electricity connections by the CPSU. In case, no electricity infrastructure exists in the area, new infrastructure as per the scope of the scheme shall be created by the CPSU following the above procedures in association with the state utility and the state government.

- On sanction of the DPR by the state, the CPSU will take up implementation of the scheme and complete the work within 12 months of the DPR sanction and will hand over the created infrastructure to the state utility for operation and maintenance. An appropriate commission shall consider the expenditure incurred by the CPSUs for scheme implementation for determining the tariff of the CPSU generating station. Operation and maintenance of the infrastructure will be the state utility's responsibility at its own expense.

[28] Report of The Working Group on Power for XII Plan (2012-17), MoP, January, 2012

The MoP in its 2010 report, 'The Economic case to Stimulate LED lighting in India', has recognised this scheme as a key demand aggregation platform for LED replacement lamps in BPL households. However as the scheme was only launched in 2009-10, there has not been any significant progress. As per the scheme, it is the responsibility of state utilities and district administration to prepare a list of BPL households in the vicinity of CPSUs in order to assess the demand. Since there is no information available in the public domain, the scale of demand aggregation under this scheme could not be quantified.

Financial feasibility of integrating LED lamps in RGGVY

With a capacity to provide of 4.14 crore BPL households with LED replacement lamps during the 12th Plan, the lead time for implementing this demand aggregation project has been considered as five years covering approximately 80 lakh BPL households every year. These LED lamp performance parameters and first costs have considerable variation among the different manufacturers, suppliers (assembling imported components) and other component providers.

A detailed cash flow statement has been developed for a project cycle of 15 years. The overall period of assessment can go up to 27 years but is limited to 15 years for simplicity. No financing costs have been considered in the procurement of LED lamps. The overall potential for cumulative reduction in annual lighting load is around 323 MW and the resulting energy savings in 707 million kWh. The annual emission reductions resulting from the expected savings is around 601 thousand tCO_2.

The simple payback period estimated for the government funds utilised for bulk procurement of LED retrofit bulbs is around eight years. Several reasons may be attributed to such a long payback period. First, the capital investment is being phased out equally in the first five years of the project cycle. Also the entire baseline scenario is calculated considering CFL use by the BPL households. This may significantly underestimate the energy savings potential because the BPL households are assumed to replace the expired lamps with CFLs again, which may not be the actual case. Another critical revenue loss in the cash flow analysis is the avoided costs of CFL replacement do not exist as this benefit is accrued by the BPL households. Therefore there is a split incentive between the government and the BPL households targeted in the RGGVY scheme, which is contributing to greater payback periods to the government.

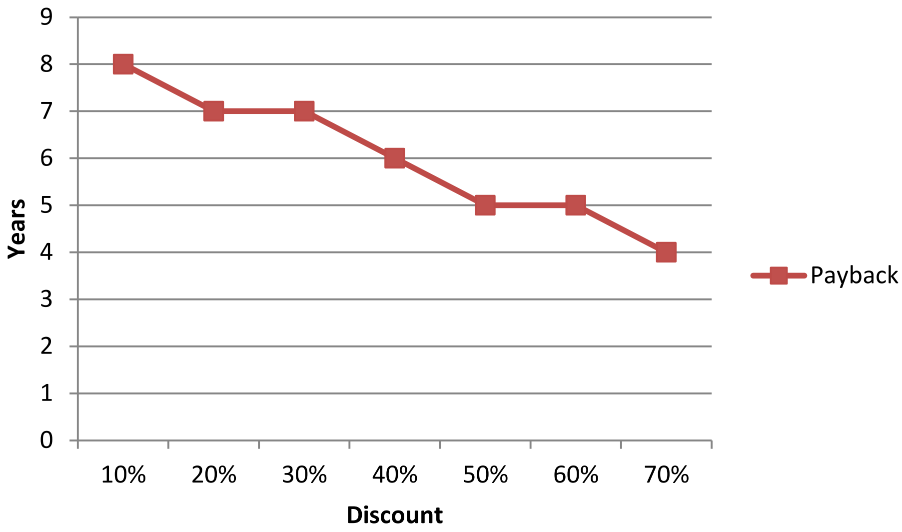
Also, the current technology of white light LEDs is still in its nascent stage and there is significant scope of improvement in this decade as discussed in earlier chapters. The current pricing of LED replacement bulbs is very high as compared to the CFL technology whereas the LED efficiency is only slightly higher. The expected reduction in prices and improvement in efficacy in the near future would fetch greater benefits to the government. Therefore phasing out maximum procurement in the last two to three years of the 12th Plan may improve the financial feasibility and payback periods.

Cost effectiveness of LED lamp deployment projects under even and uneven phasing

Procurement phasing	Cost effectiveness
Equal phasing of LED lamp procurement	Project IRR: 16%; Payback period - Eight years
Uneven phasing with maximising in last two to three years	Project IRR:22%; Payback period – Seven years

The impact of LED pricing on account of bulk purchase is currently assumed to be only 10% However this discount can vary widely based on our consultations with ELCOMA and major LED lamp suppliers in India. Hence, the pricing negotiations between the government and the suppliers (without compromising for the quality) also play a critical role in determining the cost effectiveness of LED lamp distribution under the RGGVY scheme.

Impact of bulk purchase of LED retrofit bulbs on cost effectiveness



Assumptions for financial feasibility assessment for providing LED lamps under the RGGVY scheme

Parameter	Value
Aggregated volume (No of BPL households)	41400000
No of lamps per household	1
Total number of programmes	10
No of households per programme	4140000
No of programmes per year	2
No of lamps replaced per year	8280000
Percentage of lamps defaulting every year	1%
No of days in a year	365
Hours of lamp operation per day	6
Existing lamp technology	CFL
Standard wattage of incumbent CFL lamps (in watts)	15
Luminaire efficacy of CFL (in lm per watt)	60
Initial cost of CFL lamps (INR perwatt)	10
Maximum pricerice reduction resulting from bulk procurement	10%

Average subsidy for BPL households (INR per kWh)	2.50
Monetary savings to DISCOM from peak load reduction (INR perkWh)	1.00
Tariff increase for households (per year)	5%
Current base line for electricity CO2 emission in India (kg perkWh)	0.85
Price of one CER (Euro)	10.00
Exchange rate of 1 Euro (INR)	63.40

LED replacement bulb specifications for RGGVY scheme

Characteristics of LED Retrofit lamp solutions						
Year	2012	2013	2014	2015	2016	2017
Efficacy of warm white LED bulbs (in lm/watt)	55	60	70	80	90	100
Wattage of LED bulbs equivalent to 15 watt CFL	11	11	9	8	7	6
First cost of LED replacement bulbs (INR/watt)	100	90	80	70	60	50
Life of LED replacement bulbs (hours)	25000	30000	35000	40000	45000	50000

Demand aggregation in non BPL households

This section of the report evaluates the financial feasibility of LED lighting in the domestic or residential sector. Bundling of utility driven DSM programs through a central institutional mechanism is one of the major demand aggregation strategies identified by the government. The objective is to replicate the success of CFLs, which saw 50% reduction in costs and a rise in sales; from the initial 20 million in 2002 to 250 million in 2009.

Bundling of utility driven DSM programs through a central institutional mechanism

In this demand aggregation strategy, utilities may assess the demand for LED lighting.The same may be bundled further to increase the geographical scope from utility to state, state to region (a group of states) and region to a national level. The demand aggregation can take place through a central institutional mechanism (CIM). These projects may be given out for aggregated procurement through a competitive bidding mechanism to ensure substantial price reductions in the cost of procuring LED lighting. Mandatory standards of performance, domestic manufacturing of LED lighting components, extended warranty periods can also be integrated into the procurement guidelines of LED replacement lamps by the CIM.

This report has segregated the overall general lighting demand for most of the utilities in India (excluding some privately owned utilities). The general lighting demand is derived from the electricity sales data to domestic consumers (see Table 22). The northern and southern regions have the highest demand for general lighting in residential sector followed by the western, eastern and north eastern regions.

There are many cost recovery mechanisms that are adopted worldwide for such aggregated procurement and distribution models. The LED replacement lamps may be delivered at the cost of existing light sources and the difference in first cost may be covered by the sale of certified emission reductions (CERs) under the clean development mechanism(CDM) of the Kyoto Protocol. This model is similar to the CFL distribution programs adopted by various states across the country. For some utilities, general lighting in residential sector may directly contribute to the system (GRID) peak and therefore, any savings resulting from LED lighting programs can be more than just the average cost of supply. The marginal cost of power supply during any period of active general lighting load should be the actual savings derived by the utilities. However, this marginal cost varies over utilities across the country. Utilities with very high marginal cost can provide a portion of savings as incentives, either directly to the consumers or the suppliers, to further reduce the first cost of LED replacement lamps in the market.

Table 22: General lighting demand in the domestic sector as per utility

Region	Utility	Domestic electricity sales for 2012-13 (in MWh)[29]	Domestic electricity consumption for general lighting (in MWh)[30]	General lighting demand in (MW)[31]
Eastern				
Bihar	BESB	2481	744	510

[29] Extrapolated from the yearly sales data provided in the reports on 'performance of state power utilities for the years 2007-08 to 2009-10 and 2008-09 to 2010-11', by Power Finance Corporation
[30] Estimated by considering 25-30% of the overall domestic electricity consumption
[31] Estimated by considering 1460 hours of average annual operation of general lighting equipment in Indian households

Jharkhand	JSEB	3718	1115	764
Orissa	CESCO	1949	585	400
	NESCO	921	276	189
	SESCO	708	212	145
	WESCO	900	270	185
Sikkim	Sikkim PD	51	15	10
West Bengal	WBSEDCL	6368	1910	1309
Sub total				**3513**
North eastern				
Arunachal Pradesh	Arunachal PD	76	23	16
Assam	APDCL	1289	387	265
Manipur	Manipur PD	180	54	37
Meghalaya	MeECL	271	81	56
Mizoram	Mizoram PD	228	68	47
Nagaland	Nagaland PD	251	75	52
Tripura	TSECL	383	115	79
Sub total				**550**
Northern				
Delhi	NDPL	3374	844	578
Haryana	DHBVNL	3595	899	616
	UHBVNL	2770	693	474
Himachal Pradesh	HPSEB	1855	557	381
J&K	J&K PDD	1327	398	273
Punjab	PSEB	9098	2274	1558
Rajasthan	AVVNL	2522	631	432
	JDVVNL	2234	558	382
	JVVNL	4125	1031	706
Uttar Pradesh	DVVN	2129	639	437
	KESCO	1299	390	267
	MVVN	3480	1044	715
	Poorv VVN	5249	1575	1079
	PaschiVVN	5379	1614	1105
Uttarakhand	UtPCL	1650	495	339
Sub total				**9343**
Southern				
Andhra Pradesh	APCPDCL	6797	1699	1164
	APEPDCL	3401	850	582
	APNPDCL	3816	954	654
	APSPDCL	4601	1150	788
Karnataka	BESCOM	5187	1297	888
	CHESCOM	855	214	146
	GESCOM	966	242	165
	HESCOM	1303	326	223
	MESCOM	1173	293	201

Kerala	KESB	7885	1971	1350
Tamil Nadu	TNEB	18704	4676	3203
Puducherry	Puducherry PD	625	156	107
Sub total				**9471**
Western				
Chhattisgarh	CSPDCL	3997	999	684
Goa	Goa PD	836	209	143
Gujarat	DGVCL	1953	488	334
	MGVCL	1959	490	335
	PGVCL	2879	720	493
	UGVCL	1561	390	267
Madhya Pradesh	MP Central	2161	540	370
	MP West	2502	626	428
	MP East	1915	479	328
Maharashtra	MSEDCL	16011	4003	2742
Sub Total				**6126**
Total				**29003**

Financial feasibility of bundling utility driven LED lighting programmes

The financial feasibility presented in this section assumes a hypothetical demand and evaluates the feasibility of replacing T12, T5, T8, CFL and ICL lamps bundled under any utility, state or region. This report considers a bundled demand of 600 MW of general lighting load for evaluating the payback periods for replacement of conventional lamps. **Table 23** presents the whole set of assumptions in terms of aggregated demand, cost of energy saved, energy use by various lamps, prices of luminaries etc. considered for this analysis. The assumptions pertaining to LED replacement lamp characteristics are taken from the discussion in earlier chapters (market reconnaissance of LED lamps in India).A 10% discount in LED lamp prices is assumed for aggregated procurement of large volumes. However this is only indicative, the actual impact of a bulk purchase should be tested with a pilot procurement.

Table 23: Assumptions for evaluation of payback periods for use of LED lamps in the Indian residential sector

Parameter	Value	Unit
demand aggregation parameters		
Aggregated volume of T12 replacements	3500000	No of lamps
Aggregated volume of T8 replacements	2400000	No of lamps
Aggregated volume of T5 replacements	2000000	No of lamps
Aggregated volume of CFL replacements	12000000	No of lamps
Aggregated volume of ICL replacements	1500000	No of lamps
Energy use and price parameters		

Incandescent	60	Watts
T12	52	Watts
T8	38	Watts
CFL	15	Watts
Electricity tariff	4.5	Rs/kWh
Tariff increase for Non BPL households	5%	per year
Current base line for electricity CO2 emission in India	0.85	kg/kWh
Price of one CER	10	Euro
Exchange rate of 1 Euro	63.4	Rs
Cost parameters		
Current market price of CFL	10.00	Rs/watt
Current market price of ICL	0.25	Rs/watt
Current market price of T8	1.15	Rs/watt
Current market price of T5	4.00	Rs/watt
Current market price of T12	1.00	Rs/watt
Other parameters		
No of days in a year	365	Days
Hours of operation per day	4	Hours

For the purpose of simplification, all analysis is carried out for a cycle of 15 years and a lead time of 1 year is assumed for distribution of LED luminaries in these projects. This lead time may depend upon the institutional capacity set up for implementing such projects.

Payback periods

The payback period is clear reflection of the current status and future trend of LED lighting technology. For T12 replacements, the most desirable payback of 'less than one year' is expected to be achieved only by 2020. For T8 and T5 replacements the same can be expected after 2021. For CFLs and ICLs, the LED replacement is expected to achieve the most desirable payback of 'less than one year' by 2018 and 2016 respectively (see Table 24).

Table 24: Payback periods for use of LED replacement lamps by Indian households

Year of introduction	2013	2014	2015	2016	2017	2018	2019	2020	2021
T12	11	8	6	5	4	2	2	<1	<1
T8	>15	12	9	7	5	3	2	2	2
T5	>15	>15	12	9	6	4	3	2	2
CFL	11	7	5	3	2	<1	<1	<1	<1
ICL	2	2	2	<1	<1	<1	<1	<1	<1

Demand aggregation in commercial buildings

This section of the report evaluates the financial feasibility of LED lighting in Indian commercial buildings. The overall general lighting demand estimated in these buildings is around 11 GW (refer to earlier chapters under the task of estimating space lighting demand). Approximately 2 GW of this demand can be accounted for public sector buildings and the remaining 9 GW for private sector buildings. For private commercial buildings there are no specific demand aggregation strategies proposed by the experts in the industry. However, 'The Economic Case to Stimulate LED Lighting in India' published by MoP in April, 2010, has indicated that the mandatory legislation for the use of LED lamps by the state and central procurement agencies including CPWD may generate sufficient demand for LED lighting in public sector commercial buildings.

The financial feasibility presented in this section considers a hypothetical demand and evaluates the feasibility of replacing T12, T5, T8, and CFL lamps bundled under any central institutional mechanism.

Table 25 presents the whole set of assumptions in terms of aggregated demand of luminaries, cost of energy saved, energy use by various lamps, prices of luminaries etc. considered for this analysis. The assumptions pertaining to LED replacement lamp characteristics are taken from the discussion in earlier chapters (market reconnaissance of LED lamps in India). 10% discount in LED lamp prices is assumed for aggregated procurement of large volumes.

Table 25: Assumptions for evaluation of payback periods for use of LED lamps in Indian commercial buildings

Parameter	Value	Unit
demand aggregation parameters		
Aggregated volume of T12 replacements	135	No of lamps in lakh
Aggregated volume of T8 replacements	105	No of lamps in lakh
Aggregated volume of T5 replacements	67	No of lamps in lakh
Aggregated volume of CFL replacements	467	No of lamps in lakh
Energy use and price parameters		
T12	52	Watts
T8	38	Watts
CFL	15	Watts
Electricity tariff	6	Rs/kWh
Tariff increase for commercial buildings	5%	per year
Current base line for electricity CO2 emission in India	0.85	kg/kWh
Price of one CER	10	Euro
Exchange rate of 1 Euro	63.4	Rs.
Cost parameters		
Current market price of CFL	10.00	Rs/watt

Current market price of ICL	0.25	Rs/watt
Current market price of T8	1.15	Rs/watt
Current market price of T5	4.00	Rs/watt
Current market price of T12	1.00	Rs/watt
Other parameters		
No of days in a year	365	Days
Hours of operation per day	8	Hours

For the purpose of simplification all analysis is carried out for a cycle of 15 years and a lead time of 1 year is assumed for distribution of LED luminaries in these projects. This may depend upon the institutional capacity set up for implementing such projects.

Payback periods

The payback period is a clear reflection of the current status and the future trend in LED lighting technology. For T12 replacements, the most desirable payback of 'less than one year' is expected to be achieved by 2018. For T8 and T5 replacements, the same can be expected by 2019. For CFLs, the LED replacement is expected to achieve the most desirable payback of 'less than one year' by 2016:

Table 26: Payback periods for use of LED replacement lamps by commercial buildings

Year of introduction	2013	2014	2015	2016	2017	2018	2019	2020	2021
T12	5	4	3	2	2	<1	<1	<1	<1
T8	8	6	4	3	2	2	<1	<1	<1
T5	10	7	5	4	3	2	<1	<1	<1
CFL	4	3	2	<1	<1	<1	<1	<1	<1

Demand aggregation in railway and defence establishments

Indian Railways (IR) is the single largest organisation with highest electricity consumption in India. It consumes about 2.4% of India's total electricity.[32] In the fiscal year (FY) 2010-11, Indian Railways consumed about 16.1 billion kilowatt-hours (kWh), of which 13.6 billion (about 84.5%) was for traction usages and 2.5 billion (15.5%)for non-traction usages (IR Year Book 2010-11). It is estimated that the total demand of electricity in the railways sector will grow at a rate of more than 9% annually. The electricity consumption is projected to be about 100.5 billion kWh by 2031-32 with the traction electrification being dominant. Therefore, an enormous energy saving potential exists in the Indian Railways (IR) for implementing energy efficiency measures and energy conservation technologies. Apart from this, electricity accounts for about 15% of the total operating expense. Thus, the possible savings in terms of electricity would have a positive effect on the operating margins of Indian Railways.

Under the guidance of the Ministry of Power, railway establishments with potential general lighting applications have been identified as a major platform for demand aggregation of LED general lighting in the country. The IR infrastructure can be broadly divided into traction and non-traction applications. The tentative scale of IR infrastructure in terms of the number of buildings is listed below:

IR infrastructure with general lighting applications

Non traction

- IR has about 8200 building facilities; 8000 stations, 100 workshops and 100 railway offices
- IR also has about 500,000 service buildings for supporting various amenities for railway employees. These service buildings include schools, hospitals, canteens, social welfare associations, etc.
- IR has about 650,000 houses (railway quarters) for employees.

Traction

- IR has about 53000 passenger coaches in its rolling stock[33]

General lighting demand in IR

For this, the team met the railway board and also consulted RDSO Lucknow to determine the tentative lighting stock and profile in each of the building type in IR infrastructure described above. The UNDP supported project document 'Improving Energy Efficiency in the Indian Railways System' published in 2011 is also another critical secondary resource for information regarding IR infrastructure and lighting stock. The Table 27 presents a tentative lighting profile in IR establishments.

In the Non traction applications, there are approximately 593,821 employee quarters (occupied), and in 2011[34] a CFL distribution scheme funded by CDM has been initiated to replace incandescent lamps in these quarters. IR had planned to distribute four CFLs to each household in the employee quarters and complete the distribution process by 2012. We have assumed that all the incandescent lamps have been successfully replaced

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[32] As per 2007-08 consumption norms represented in the UNDP project titled "Improving energy efficiency in the Indian Railways system"
[33] Rolling stock statistics in Indian Railways Year Book, 2010-11
[34] Lok Sabha unstarred question#2436, 2011

in the quarters and the existing lamp profile comprises of only CFL and linear fluorescent tubes. Apart from this, we have also assumed that about 3 T12 lamps are currently in use in each of these quarters. Therefore, the total lighting stock in staff quarters can be approximately 26 lakh CFLs and 19.5 lakh T12 linear tube lamps.

As per the information provided by the railway board, IR has reportedly replaced more than 14 lakh linear fluorescent tubes with T5 technology in service buildings, stations, workshops and administrative offices across the country in 2012. Apart from the linear tube lamps, about 4 lakh CFLs have also been replaced in the same year. Therefore, in the current situation, the same volume can be used as the best proxy of general lighting demand in the IR's non traction applications.

In the traction applications, IR also has about 53000 passenger coaches in its rolling stock and the average no of light points in each of coaches (for interior illumination) is around 70. As per the information provided by the railway board, most of the light fixtures in the conventional coaches are of T12 technology (2 foot, 28 watt)[35]. However IR has initiated the usage of LED luminaries in all its new coaches that are currently in their production phase.

Table 27: General lighting profile in IR

Application type	Existing stock buildings or establishments		Stock and profile of existing lamps
	Value	**Unit**	
Traction - passenger coaches	53000	No of coaches	37 lakh T12 linear tube lamps
Non traction - railway staff quarters	650000	No of households	19.5 lakh T12 linear tube lamps and 26 lakh CFLs
Non traction - service buildings, stations, workshops and railway administrative offices	508200	No of buildings	14 lakh T5 linear tube lamps and 4 lakh CFLs

Source: PwC assessment

Overall, one can deduce that IR has approximately one crore lamps for general lighting applications: traction (37 lakh), staff quarters (45 lakh) and non traction (18 lakh). The overall distribution of general lighting stock in IR is shown in Figure 19.

35 "Improving energy efficiency in the Indian Railways system", UNDP and IR, 2011

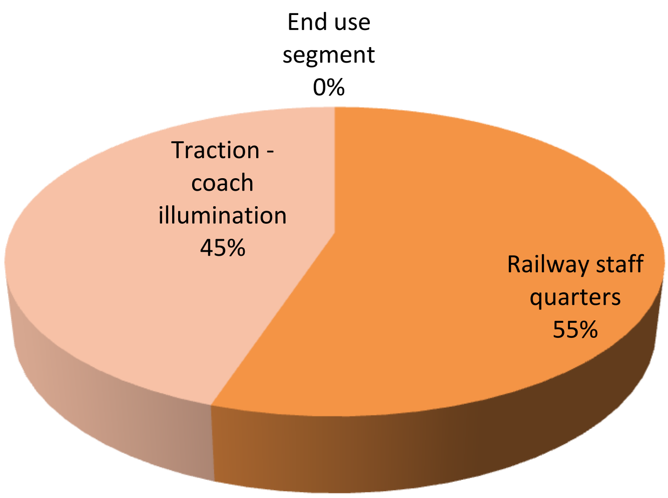


Figure 19: Share of general lighting demand in IR

Financial feasibility for replacement of general lighting lamps with LED retrofits in IR

With a market potential of 1 crore LED replacement lamps for general lighting, IR could reduce substantial amount of electricity demand and operating costs. A detailed cash flow statement has been developed for a project cycle of 15 years to assess the financial feasibility of replacing the existing general lighting stock in various end use applications in IR across the country. The financial feasibility is analysed separately for three major end use segments recognised by IR (staff quarters, traction and non traction).

A set of assumptions considered for this analysis is provided in Table 28. The LED lamp performance parameters and first costs may have considerable variations among different manufacturers, suppliers (assembling imported components) and other subcomponent providers. However, all the parameters pertaining to the LED lamp characteristics (first cost, efficacy, and useful life) have been derived from the discussion in earlier chapters, and have benchmarked the current status and future trend. The expected improvement in lamp performance and prices in future is taken into consideration while estimating the procurement costs and corresponding energy savings.

Table 28: Assumptions for financial feasibility assessment of procurement and distribution of LED lamps in IR

Project parameters		Unit
Discount on bulk purchase LED retrofits	10%	%
Annual operational hours of T12 lamps inside passenger coaches	2190	Hours
Annual operational hours of lamps in staff quarters	1460	Hours
Annual operational hours of lamps for non traction purposes	2920	Hours
Cost of electricity for coach illumination	5.5	Rs/ unit

% Increment in cost of electricity for traction and non traction applications	5%	%
Tariff for non BPL households	4.50	Rs/kWh
Tariff increase for households	5%	per year
Current base line for electricity CO2 emission in India	0.85	kg/kWh
Price of one CER	10.00	Euro
Exchange rate of 1 Euro	63.40	Rs

Clearly, the cost effectiveness of this initiative is a function of the year of introduction of LED lamps in the IR premises. We know that the current technology of white light LEDs is still in its nascent stage and there is significant scope of improvement in this decade. The expected reduction in prices and improvement in efficacy in the near future will definitely fetch greater benefits to IR. However, IR has to take a decision to assess what levels of payback period is acceptable for it to kick start the replacement of its existing general lighting stock. In order to simplify this task for IR, we have provided a sensitivity analysis of the project's cost effectiveness with the year of introduction of LED lamps:

Table 29: Payback period for LED deployment in railway premises

Year of introduction of LED lamps	Staff quarters	Traction	Non traction
2014	7.00	5.00	7.00
2015	5.00	4.00	5.00
2016	4.00	3.00	4.00
2017	3.00	2.00	3.00
2018	<1	<1	2.00

The above table shows the cost effectiveness (payback period) of replacing the existing 19 lakh T12 and 26 lakh CFL lamps in the staff quarters of IR across the country. The analysis spreads over the first cost of lamps in the initial two years of introduction The payback period for the railway employees is initially seven years in the year of 2014 gradually drops to less than one year years by end of 2018.

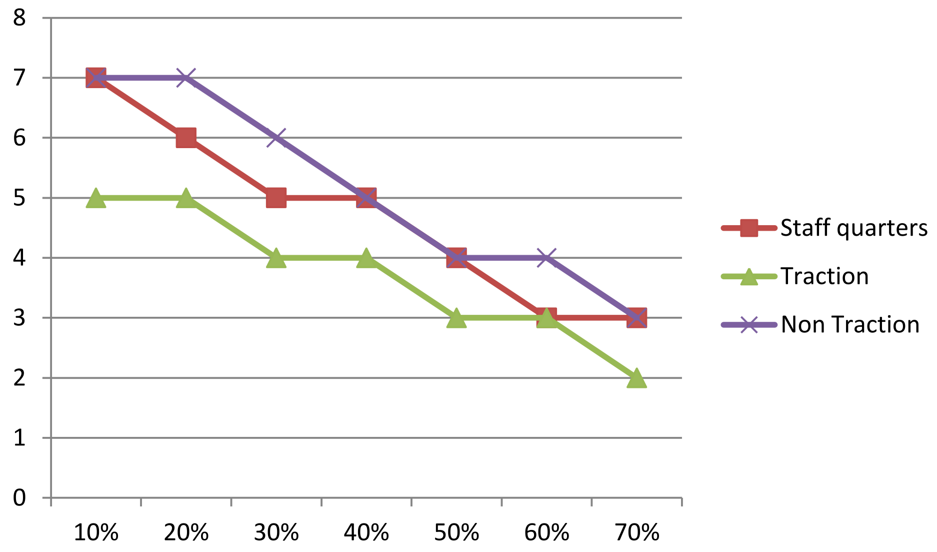
Similarly, the first cost of procuring and replacing the existing lighting stock for coach illumination is evenly distributed in the initial two years of the project cycle. The payback period for IR is five years when the project takes off next year (2014), and the same is dropping to less than one year by end of 2018.

In case of non traction applications, all the lighting stock is assumed to be replaced within one year of the introduction. The payback period for IR is seven years, when the project takes off next year (2014), and the same drops to three years by the end of 2017. The payback period in this end use segment of IR is relatively lower, because the existing stock already consists of T5 tube lamps and the LED technology may take some time to compete with T5 fluorescent technology in the general lighting market.

In all kinds of general lighting applications, the drop in payback period is the direct result of improvement in the efficiency of LED lamps and reduction in prices.

Another critical assumption driving the cost effectiveness of LED lighting in railways is the quantum of discount in LED lamp prices assumed for aggregated procurement of large volumes. This discount reflects the impact of bulk procurement on the first cost of LED luminaries supplied by the manufacturers. 10% discount is assumed for pay back periods estimated in the above mentioned table. However, this is only indicative; the actual impact of bulk purchase should be tested with a pilot procurement. Figure 20 shows an indicative impact of bulk procurement on cost effectiveness of LED lighting introduced in the year 2014.

Figure 20: Impact of bulk procurement on cost effectiveness of LED lighting in railways



The Indian defence establishments

These could be another potential demand aggregation platform for LED general lighting in the country. Some of the defence infrastructure with potential general lighting applications has been listed below:

- Dwelling units for armed forces personnel
- Dwelling units for civilian employees
- Administrative offices
- Recruitment and training academies
- Cantonment areas for armed forces personnel
- Offices of defence PSUs: HAL, BEL, BEML, BDL, MDL, GSL, GRSE, Midhani.

There is not much information available in the public domain regarding the scale of various infrastructure facilities with general lighting applications currently present under the purview of the ministry. Hence, the project team has been unable to identify and assess the demand aggregation platforms within this ministry.

Roadmap for demand aggregation of LED lighting

This section entails a roadmap for implementing the LED demand aggregation options discussed in this report. This roadmap is intended to accelerate the LED based general illumination products (specifically the retrofit models) adopted by the market, to enhance commercial adoption of those products, and to maximise energy savings.

Demand aggregation in BPL households

The key element for realising the benefits of demand aggregation is a CIM that can undertake the required bulk procurement of LED retrofit lamps and achieve the expected price reductions. In the current model of BPL electrification under RGGVY, the implementing agencies are the state owned electric utilities which seek funding of electrification projects in their respective jurisdiction. There is no provision for demand aggregation in this model. This model has to be corrected to incorporate a centralised institution for procuring LED retrofit lamps for all the projects sanctioned in a particular time frame.

Apart from this, our consultation with ELCOMA has indicated that large volume orders (ideally in millions) have the potential to decrease prices of LED retrofit lamps as low as INR 300 per lamp. However, this is just an indicative limit. The proposed CIM should test this limit with a pilot procurement of a size greater than 1 million. This exercise would also reinforce some credibility in the prospective benefits of demand aggregation among the potential stakeholders.

One should also remember that the current technology of white light LEDs is still in its nascent stage and there is a significant scope of improvement in this decade. The current pricing of LED replacement bulbs is very high as compared to the CFL technology whereas the LED efficiency is only slightly higher. The expected reduction in prices and improvement in efficacy in the near future would bring in greater benefits to 12th Plan lan may improve the financial feasibility of government funds utilised to procure LED retrofit lamps.

The roadmap for demand aggregation in BPL households can be summarised in the following points:

- *Establish a CIM for procuring LED retrofit lamps for all the sanctioned projects within a defined time frame.*
- *Undertake a pilot procurement with at least 1 million lamps to test the impact of bulk purchase on LED lamp pricing.*
- *Phase out the overall target for the 12th Plan so that the maximum procurement of LED retrofit lamps can be done in the final 3 years..*

Demand aggregation in non BPL households

In this strategy, the state's nodal agencies for energy conservation can play an effective role. These agencies can bundle several projects across the state and give them out for bulk procurement through a competitive bidding mechanism to ensure substantial price reductions in the cost of procuring LED lighting. They may test the impact of bulk procurement on LED lamp prices with a pilot procurement greater than 1 million. Mandatory standards of performance, domestic manufacturing of LED lighting components, extended warranty periods can also be integrated into the procurement guidelines of LED replacement lamps.

The current retrofit lamp market can be broadly divided into: LED bulbs, which can replace ICLs and CFLs, and LED tubes, which can replace fluorescent tube lamps. The improvement in LED technology and efficiency in the near future may benefit the LED retrofit bulb market but the LED retrofit tubes may take a while to compete with the T5 technology. The T5 technology may be the dominant choice of lighting by residential consumers in the next 4 to 5 years. Therefore, the state nodal agencies should focus mainly on enhanced penetration of LED retrofit bulbs during the 12th Plan.

Apart from this, the BEE may also integrate LED retrofit bulbs into the BLY scheme so that the LED retrofit bulbs may be delivered at the cost of conventional light sources and the difference in first cost may be covered by the sale of CERs under the CDM of the Kyoto Protocol. In order to facilitate this, the BEE may develop a separate programme of activities for LED retrofit bulbs that can support the private investors in implementing the CDM programme activities in India through collaboration with electricity distribution companies (DISCOMs).

Exemption from VAT can also be used as an effective policy tool to reduce LED lamp prices in various states. In some states, LED luminary products are bought under the highest slab of VAT (@14.5%). Therefore, exemption from VAT by state governments could further lower the cost of LED luminaries beyond the bulk purchase discounts availed through demand aggregation. For an average annual sales volume of 1 million LED luminaries in a state in India, the state's exchequer may incur an expenditure of 11.6 crore[36] (approximately) by way of introducing VAT exemption for LED luminaries. However, 1 million LED retrofit lamps into the state's grid would reduce the annual lighting demand by 6 MW directly contributing to the state's peak demand reduction. In this regard, the state may also avoid 6.73 MW[37] (approximately) of capacity addition to meet the peak demand, clearly translating into INR 40 crore[38] of savings in capital investments for power plant infrastructure.

The roadmap for demand aggregation in non BPL households can be summarised in the following points:.

- *The state nodal agencies for energy conservation must be entrusted the responsibility for demand aggregation of LED retrofit lighting at the state level.*
- *These agencies may test the impact of bulk procurement on LED lamp prices with a pilot procurement greater than 1 million.*
- *Exemption from VAT can be used as an effective policy tool to reduce LED lamp prices in various states.*
- *The bulk procurement agencies should focus mainly on enhanced penetration of LED retrofit bulbs during the XII plan as the LED retrofit tubes may take a while to compete against the incumbentT5 technology.*
- *The BEE may develop a separate PoA for LED retrofit bulbs and integrate LED lighting in the current BLY scheme.*

Demand aggregation in commercial buildings

There are no definite strategies for demand aggregation that can result in bulk procurement of large volumes in private commercial buildings. However, the government has considered many policy directives to generate enough demand and accelerate the penetration of LED lighting in the commercial buildings. 'The Economic Case to Stimulate LED Lighting in India' published by MoP in April, 2010, has indicated that the mandatory legislation for use of LED lamps by the state and central procurement agencies including CPWD may generate sufficient scale of demand for LED lighting in public sector commercial buildings.

[36] Sale of one LED luminary (equivalent to 15 watt CFL) would generate INR 116 by way of VAT imposition (@14.5%); market price of LED luminary in today's scenario is assumed to be INR 800 per lamp (inclusive of VAT)
[37] Considering 20% T&D losses; 78% PLF; and peak coincidence factor of 0.7
[38] Capital investment in power plant infrastructure is assumed to be INR 6 crore / MW

The government may also consider introducing accelerated depreciation benefits (under Section 32 Rule 5 of the Income Tax Act, 1961) for LED based general lighting systems. This incentive may substantially reduce the ownership cost of LED lighting for commercial purposes and mitigate the high first cost barrier existing in the current scenario. For an annual national sales volume of 10 million LED luminaries[39] today, the country's exchequer may incur a financial loss of 99 crore[40] by way of introducing accelerated depreciation for LED based general lighting systems. However, 10 million LED luminaries into the nation's grid would reduce the annual lighting demand by 60 MW directly contributing to the country's peak demand reduction. In this regard, the country may also avoiddelay 67.3 MW[41] (approximately) of capacity addition to meet the peak demand requirements, clearly translating into INR 400 crore[42] of savings in capital investments for coal based power plant infrastructure. Apart from these benefits, the scale of annual energy savings would be 88 million units (approximately) and the corresponding annual emission reductions would be 75 thousand tonnes of CO2 (approximately).

Exemption from VAT by state governments can also reduce the prices of LED luminaries for commercial purposes. The scale of impact brought in by this policy instrument is illustrated in the previous section.

Apart from this, BEE may in time revise the lighting parameters defined in Energy Conservation Building Code(ECBC) introduced in 2007. The interior lighting power density, which evaluates the total wattage of lighting fixtures per sqm of gross lit area, is an ideal parameter that can regulate the lighting efficiency in commercial buildings.

The roadmap for demand aggregation in commercial buildings can be summarised in the following point:

- *Introduce mandatory legislation for use of LED lamps by state and central procurement agencies including CPWD.*
- *Introduce accelerated depreciation benefits* (under Section 32 Rule 5 of the Income Tax Act 1961) for LED based general lighting systems.
- *Encourage state governments for exemption from VAT for purchases of LED luminaries for commercial purposes.*
- *BEE may in time revise the lighting parameters defined in ECBC introduced in 2007.*

Demand aggregation in railway and defence establishments

The current procurement system for general lighting in IR is a decentralised system at adivisional level for service buildings, station premises, production units, and workshops. IR should bundle all the general lighting demand across the traction and non traction applications and centralise the procurement through the railway board. IR has already gained the experience of bundled procurement described above for CFL

procurement through a tender floated by the railway board in 2008[43]. This tender sought the services of a CFL

[39] The national sales volume of 10 million LED luminaries is considered for general demonstration and market value of this volume of transaction is slightly under the INR 990 crore of market size of LED luminaries predicted by the Mckinsey's 2012 global lighting market model

[40] Market price of LED luminary today is assumed to be INR 800 per lamp; book depreciation is assumed to be 7% under normal depreciation ; net depreciation under the accelerated case would be INR 800*(80%-7%), which is equal to INR 584 benefit per lamp. The resulting net tax benefit is estimated by considering a MAT rate @16.995%, which is equal to INR 99 per lamp.

[41] Considering 20% T&D losses; 78% PLF; and peak coincidence factor of 0.7

[42] Capital investment in power plant infrastructure is assumed to be INR 6 Crore / MW

[43] Railway board tender no. 2008/Elect (Dev)/ 225/9 dated 23.06.08, titled 'Improving energy efficiency in lighting loads in railways' residential quarters over Indian Railway zones, Production Units & Workshops by replacing an estimated number of 26 lakh (±30%) incandescent lamps with compact fluorescent lamps (CFLs) under Clean Development Mechanism' in 2008.

supplier to supply lamps to a list of nominated consignees in the tender. The supplier had to incur the transport expenses of the CFLs and ensure that the required no of CFLs was received by the nominated consignees within a predefined timeframe. The distribution of CFLs was further entrusted to these consignees. Such a procurement system could be repeated with some refined guidelines incorporating the mandatory standards of performance, domestic manufacturing of LED lighting components, extended warranty periods etc.

This centralised procurement may be undertaken for its existing lighting stock illuminating the passenger coaches (traction). IR may derive substantial price reductions in LED luminaries' prices by bundling the existing demand. IR has also already directed its coach production units and factories to install LED lighting in all its newly manufactured coaches. All the demand arising from manufacturing the new coaches within a short time frame (less than 1 year) can be bundled and a centralised procurement can be undertaken through a competitive bidding. This can also help IR in testing the impact of bundled procurement on LED lamp prices.

Additionally the government may also grant accelerated depreciation benefits to IR for purchasing LED luminaries for general lighting purposes (excluding the staff quarters). This will substantially reduce the prices of LED luminaries procured by IR.

For non traction purposes, T5 and CFLs already dominate the existing stock. As discussed earlier, the improvement in LED technology and efficiency in the near future may benefit the LED retrofit bulb market but the LED retrofit tubes may take a while to compete with the T5 technology. The T5 technology may be the dominant choice of lighting in the next 4-5 years. Therefore, for replacing its existing lighting stock, the IR should initially focus on enhanced penetration of LED retrofit bulbs and then wait for the LED retrofit tube market to mature.

The Indian defence establishments should initially quantify the existing lighting stock (by technology and application) either by undertaking a survey or through internal directives to all its procurement officers. This evaluation would help the Defence Ministry to assess the general lighting demand and further evaluate the energy saving potential for LED based lighting. The ministry may further adopt a centralised procurement system for lighting to derive substantial price reductions in LED luminary prices.

The roadmap for demand aggregation in railway and defence establishments can be summarised in the following points:

- *IR may bundle all the lighting demand in its newly manufactured coaches across all the production units and workshops and further undertake a centralised procurement of LED luminaries to test the impact of bundled procurement on LED luminary prices.*
- *IR may further bundle all the existing lighting demand for coach illumination and further undertake a centralised procurement of LED luminaries to derive substantial price reductions in LED luminary prices.*
- *The government may also grant accelerated depreciation benefits to IR for purchasing LED luminaries for general lighting purposes (excluding the staff quarters).*
- *For non traction purposes, which currently demand only retrofit products, IR may focus on enhanced penetration of LED retrofit bulbs and wait for the LED retrofit tube market to mature.*
- *The Indian defence establishments should initially quantify the existing lighting stock (by technology and application) either by undertaking a survey or through internal directives to all its procurement officers.*
- *The Defence Ministry may further adopt a centralised procurement system for lighting to derive substantial price reductions in LED luminary prices.*

Closing statement

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