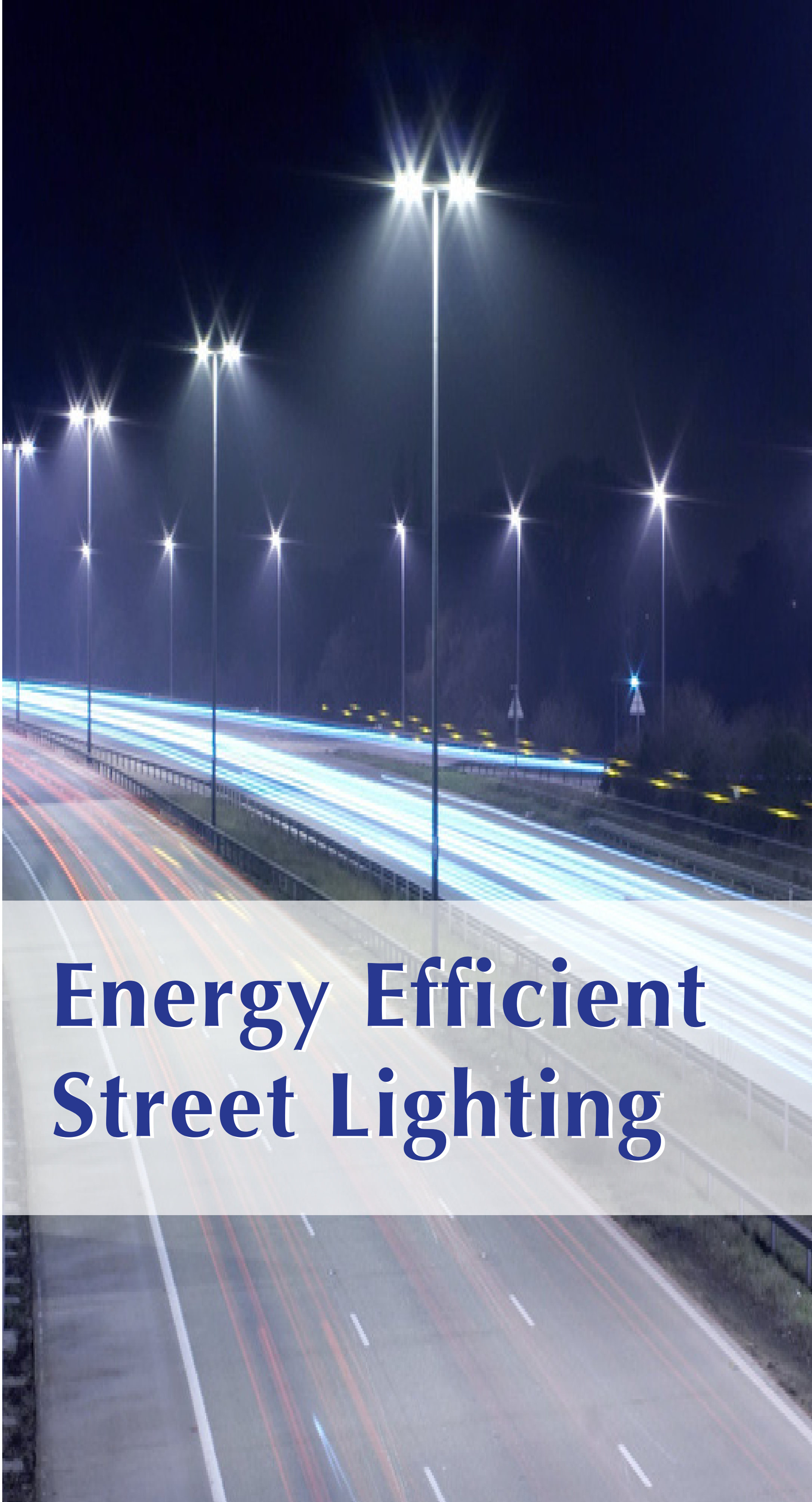

Guidelines

Energy Efficient Street Lighting

USAID | INDIA
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ENERGY IS LIFE
BEE
CONSERVE IT

Background

Providing street lighting is one the most important – and expensive – responsibilities of a city: Lighting can account for 10–38% of the total energy bill in typical cities worldwide (NYCGP 2009). Street lighting is a particularly critical concern for public authorities in developing countries because of its strategic importance for economic and social stability. Inefficient lighting wastes significant financial resources each year, and poor lighting creates unsafe conditions. Energy efficient technologies and design can cut street lighting costs dramatically (often by 25-60%); these savings can eliminate or reduce the need for new generating plants and provide the capital for alternative energy solutions for populations in remote areas. These cost savings can also enable municipalities to expand street lighting to additional areas, increasing access to lighting in low-income and other underserved areas. In addition, improvements in lighting quality and expansion in services can improve safety conditions for both vehicle traffic and pedestrians.

A well-designed, energy-efficient street lighting system should permit users to travel at night with good visibility, in safety and comfort, while reducing energy use and costs and enhancing the appearance of the neighborhood. Conversely, poorly designed lighting systems can lead to poor visibility or light pollution, or both. Quite often, street lighting is poorly designed and inadequately maintained (e.g., there are large numbers of burned-out lamps), and uses obsolete lighting technology—thus consuming large amounts of energy and financial resources, while often failing to provide high-quality lighting. The Bureau of Energy Efficiency, based on Central Electricity Authority statistics, has estimated gross energy consumption for public lighting to be 6,131 million kWh in India for the years 2007-2008.

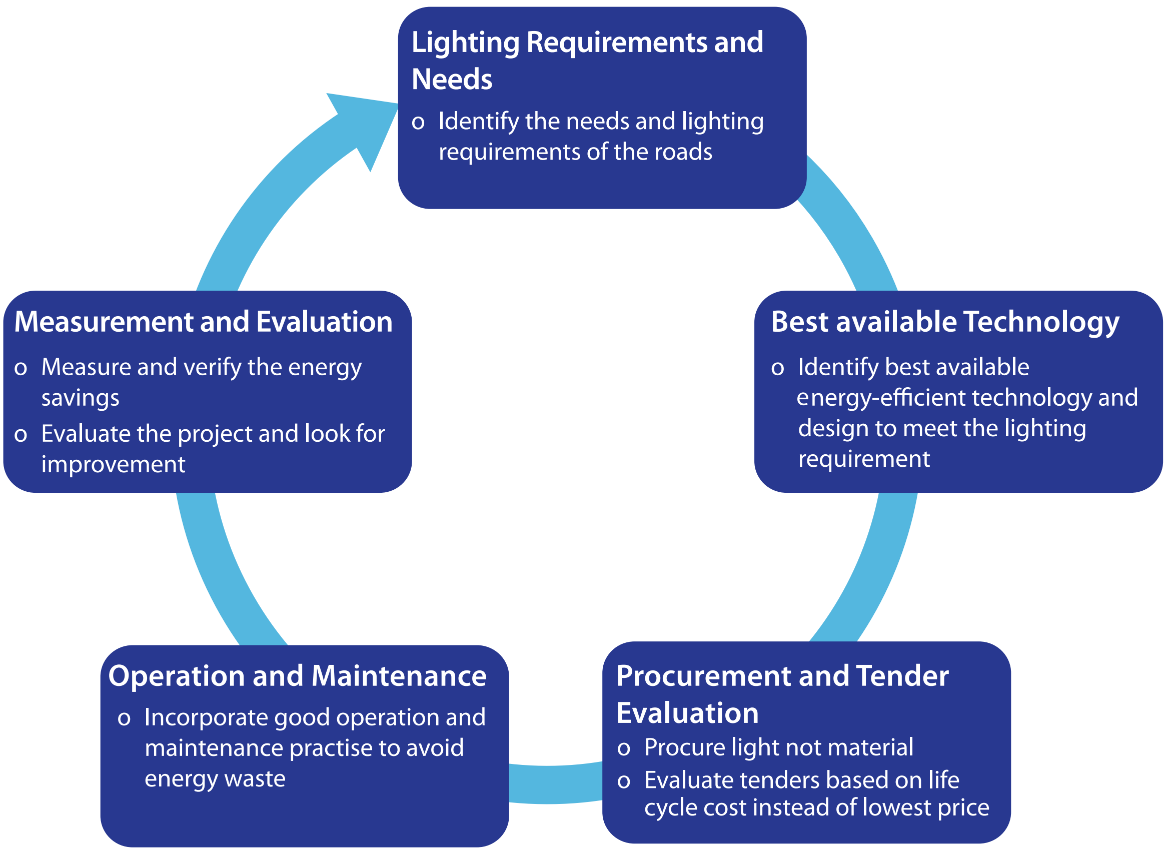
Energy-efficient Street Lighting

Energy-efficient street lighting projects have several stages, as illustrated in Figure 1.

In the last few years, technological advancements in lighting have led to the development of energy-efficient lighting systems that consist of one or more components listed below:

- Low loss ballasts
- Constant wattage high intensity electronic ballasts
- Energy-efficient luminaires
- Better monitoring and control mechanisms

Figure 1: Energy-efficient Street Lighting Project Cycle



Guidance for lighting of public streets, roads, and highways is provided in the Indian Standard (BIS, 1981). Since these guidelines are not enforced by any regulatory authority, it is common for municipalities to be unaware of the standards, and many fail to comply.

The most common reasons for inefficient street lighting systems in municipalities are:

- Selection of inefficient luminaires
- Poor design and installation
- Poor power quality
- Poor operation and maintenance practices

There is tremendous potential to improve lighting quality while reducing energy use, costs, and greenhouse gas emissions—through energy-efficient retrofits for street lighting and improved operation and maintenance (O&M) practices.

The purpose of these guidelines is to increase the awareness about the Bureau of Indian Standards (BIS) Code of Practice for lighting of public thoroughfares and to provide practical guidance on energy-efficient street lighting best practices. Since the Code has not been updated since 1981, these guidelines can also contribute to the development of future standards. Although the main target audience is municipalities, all stakeholders interested in street lighting projects—such as regulatory bodies, technology suppliers, donor agencies, corporations, and universities with campuses—can benefit from these guidelines.

Effective energy-efficient street lighting design integrates efficient lamp technologies, optimum pole height and placement, efficient light distribution, and aesthetics while using the least energy and meeting requirements for visibility and appropriate light levels (NYSERDA, 2002).

Guidelines for Decision Making in Street Lighting Projects

Lighting Requirements in Streets

When designing or making changes in street lighting, it is important to first understand the light requirements of the road. Street lighting in India is classified in the Indian Standard (BIS, 1981), based on the traffic density of the road (see Table 1). Based on the classification in the code, the local engineer matches the category of road, and designs and provides installation specifications for the street lighting system.

Retrofit or New Installation

Based on the purpose and lighting requirements of the roadway as well as the age of the existing lighting infrastructure, decisions have to be taken whether new design and installation of street lighting is required, or whether project goals can be accomplished by retrofitting the existing lighting system. To retrofit existing street lighting, it must be determined whether existing poles can be used with replacement of only the luminaires, or if the

Table 1: Classification of Roads (BIS, 1981)

Group	Description
A1	For very important routes with rapid and dense traffic where the only considerations are the safety and speed of the traffic and the comfort of drivers
A2	For main roads with considerable mixed traffic like main city streets, arterial roads, and thoroughfares
B1	For secondary roads with considerable traffic such as local traffic routes, and shopping streets
B2	For secondary roads with light traffic
C	For residential and unclassified roads not included in the previous groups
D	For bridges and flyovers
E	For towns and city centers
F	For roads with special requirements such as roads near airports, and railways

ground needs to be dug up to construct new bases and trenches for laying cables (NYSERDA, 2002).

Retrofitting

Retrofitting is generally considered for energy and maintenance savings. Sometimes it is necessary to retrofit or replace luminaires or a pole – e.g., in cases where light is not distributed correctly, or where a pole has been damaged. Opportunities for significant efficiency improvements are limited in these cases, since the pole location does not change (NYSERDA, 2002).

New Installation or Replacement

This option involves removing existing street lighting and installing new equipment, or designing and installing a completely new system where street lighting did not previously exist. This option provides greater flexibility in the design with regard to location and number of poles. If a main street improvement project is planned, new poles and lighting fixtures may be the best option for the most effective energy-efficient design of the street lighting system.

Technical Assessment of Street Lighting Technologies for Energy Efficiency

Lighting components can be grouped based on their functions. They are generally described as the structural systems, electrical systems, and optical systems. The items covered include:

Structural

- Poles
- Pole Bases (foundations)

Optical

- Luminaires

Electrical

- Lamps
- Ballasts
- Service Cabinets (fuse box)

All systems should be designed to minimize life-cycle cost, while meeting lighting requirements (e.g., minimum illuminance requirements to ensure proper functioning and safety of users). To achieve an effective energy-efficient design, it is essential to select the proper lamp/ballast combination that produces high lumens per watt together with fixtures that meet design requirements and minimize glare, light trespass, and light pollution.

Lamp Technology

The most important element of the illumination system is the light source. It is the principal determinant of the visual quality, cost, and energy efficiency aspects of the illumination system. An electric light source is a device, which transforms electrical energy, or power (in watts), into visible electromagnetic radiation, or light (lumens). The rate of converting electrical energy into visible light is called "luminous efficacy" and is measured in lumens per watt.

The types of lamps commonly used for street lighting are listed in Table 2 with brief descriptions. While the

Table 2: Lamp Technology

Type of Lamp	Luminous Efficacy (lm/W)	Color Rendering Properties	Lamp life in hrs	Remarks
High Pressure Mercury Vapor (MV)	35-65 lm/W	Fair	10,000-15,000	High energy use, poor lamp life
Metal Halide (MH)	70-130 lm/W	Excellent	8,000-12,000	High luminous efficacy, poor lamp life
High Pressure Sodium Vapor (HPSV)	50-150 lm/W	Fair	15,000- 24,000	Energy-efficient, poor color rendering
Low Pressure Sodium Vapor	100-190 lm/W	Very Poor	18,000-24,000	Energy-efficient, very poor color rendering
Low Pressure Mercury Fluorescent Tubular Lamp (T12 &T8)	30-90 lm/W	Good	5,000-10,000	Poor lamp life, medium energy use, only available in low wattages
Energy-efficient Fluorescent Tubular Lamp (T5)	100-120 lm/W	Very Good	15,000-20,000	Energy-efficient, long lamp life, only available in low wattages
Light Emitting Diode (LED)	70-160 lm/W	Good	40,000- 90,000	High energy savings, low maintenance, long life, no mercury. High investment cost, nascent technology

luminance on the road surface (the intensity of light, or the amount of light per unit area of its source traveling in a particular direction) can vary widely and still provide the required performance, the measurement of illuminance (amount of light or total luminous flux incident on a surface, per unit area – it is easier to measure illuminance than luminance) can still be used as a benchmark indicator to signal required lamp replacement or cleaning.

Energy Saving Tip

By replacing all high pressure mercury vapor lamp fittings in street lighting with high pressure sodium vapor lamps with slightly lower wattage, savings of 20-25% can be achieved.

Selection of Lamps

Street lighting installations normally use one of three types of high intensity discharge (HID) lamps: high pressure sodium vapor (HPSV), metal halide (MH), or mercury vapor (MV). HSPVs produce a yellowish light, have a long life, are very energy-efficient, and have good lumen maintenance (maintain light output for a long period of time), but have poor color rendering properties. MH lamps are the most frequently used alternative to HPSV in new installations. They are also quite efficient and provide much better color rendering. However, these lamps tend to have a shorter lamp life (some models below 10,000 hours) and poor lumen maintenance over the life of the lamp. Recent developments have shown improvements in these areas, but the improved lamps are presently limited in supply and higher in cost. MV lamps are the least efficient of the HID types and have poor lumen maintenance.

Light-emitting diode (LED) technology is a fast-evolving technology with significant energy-saving potential. Operating for an average of 10 hours per day, LEDs have a life span of up to 13 years, and provide a pleasant spectrum of light (Masthead LED Lighting, 2009). The lifetime and performance depends on quality of the LED, system design, operating environment, and other factors such as the lumen depreciation factor over a period of time.

Although the upfront cost of the LED is more than the cost of most HID lamps, the energy consumed by the LED is half of the lamp's energy (or less) and LEDs last longer than conventional lamps, resulting in significant savings. The LED fixture does not require a ballast or a capacitor;

instead it converts the supply voltage to low voltage direct current, using a small electronic power supply.

Ballasts

Ballasts are required for all HID and fluorescent lamps. The ballast generally serves three functions. First, it provides the proper open circuit voltage to start the lamp. Second, it keeps the lamp operating within its design parameters. Third, it adapts the lamp to any one of the line voltages commonly available.

Sodium vapor and metal halide lamps require an igniter to initiate the arc in the lamps. High frequency electronic ballasts are recommended for tubular fluorescent lamps in street lighting in order to optimize energy use and to avoid flickering during low voltage conditions at peak traffic hours. Another useful technology to save energy in HPSV and MH lamps is the new dimmable electronic ballast that enables both constant wattage and variable illumination. The advantage of this ballast is the maintenance of desired lux level (illumination level) during low and high voltage periods at night, which helps ensure good visibility for road users during peak traffic hours. In addition, capacitors and igniters are not required when using this technology, which brings down the maintenance costs.

Luminaires

Lighting energy efficiency is a function of both the light source (the light "bulb" or lamp) and the fixture, including necessary controls, power supplies, other electronics, and optical elements. A luminaire is defined as a complete unit consisting of a lamp, together with the parts designed to distribute the light, to position and protect the lamp, and to connect the lamp to the power supply. Components that make up a luminaire include the reflector, the refractor, and the housing. These are important to ensure luminaire efficiency and cutoff and glare control, to guarantee the right level of lighting while avoiding light pollution. The specification for selection of street lighting luminaires has been provided in IS 10322 Part I to Part V.

Luminaires are classified into three categories according to the degree of glare (BIS, 1981) (their application is indicated in Table 6):

A. **Cutoff luminaire:** A luminaire whose light distribution is characterized by rapid reduction of luminous intensity in the region between about 80º and the horizontal. The direction of maximum intensity may vary but should be below 65º. The principal advantage of the cutoff system is the reduction of glare.

B. **Semi-cutoff luminaire:** A luminaire whose light distribution is characterized by a less severe reduction in the intensity in the region of 80º to 90º. The direction of maximum intensity may vary but should be below 75º. The principal advantage of the semi-cutoff system is a greater flexibility in siting.

C. **Non-cutoff luminaire:** A luminaire where there is no limitation on light distribution at any angle. This luminaire is permissible when a certain amount of glare may be accepted (when daytime appearance of the street is important) and when the luminaires are large and have reduced brightness.

Design and Procurement of Energy-efficient Street Lighting Systems:

In order to properly design new lighting schemes, it is important to consider the appropriateness and effectiveness of the various energy efficient street lighting technologies and systems for different situations. Street lighting technology and design decisions should be based on meeting local lighting requirements while achieving maximum energy efficiency. Most importantly, the design of a street lighting system must be appropriate for the site and should provide the level of illumination (lux) and uniformity of light specified in the Indian Standard (BIS, 1981). Decisions about lighting systems also should take into account the relative importance in each situation of such characteristics as lamp efficacy, good color rendering, and light distribution of different types of lamps.

In addition to these criteria, other considerations may affect street lighting system design decisions. For example:

- Lighting controls such as dimming systems can result in significant energy savings, but are not appropriate for every application (see Dimming Systems section for details).

Light-Emitting Diode (LED) Street Lights

Advantages:

- *Very long life*
- *Reduced maintenance costs due to long lifetimes*
- *Do not contain toxic chemicals (e.g., mercury)*
- *No warm up needed (no time delay to reach optimum brightness levels)*
- *No production of ultraviolet light (which is what attracts insects)*
- *Useful for directing light on specific areas, since they produce "directional" light -- light emitted in one direction, rather than a diffused glow*
- *Can be dimmed (unlike CFLs), allowing for flexibility in controlling light levels*
- *High color index, providing bright, true colors during nighttime hours*
- *No glare effect, reducing visual fatigue for both drivers and pedestrians*

Disadvantages:

- *High initial costs can lead to long (several-year) paybacks*
- *Provision of only directional light (inability to produce a "glow" emanating in all directions) limits usefulness to only streetlights that are hanging or facing downward*
- *Adequate heat-sinking is required to ensure long life with high-powered LEDs*

Spotlight: *In Solar LED Lighting, solar energy is used to charge a self-contained battery during daylight; at night, the battery powers the street lights. Solar LED street lighting is an especially cost-effective solution for parking lots, parks, residential streets, airports, and other applications where providing electricity is expensive or problematic. Two additional benefits of these types of LEDs is ease of installation - since the lamps rely on solar power, there is no need to dig trenches to lay underground cables - and immunity to power outages. (Silverman, Jacob 2009; Armand Hadife n.d.)*

- Operations, maintenance and replacement costs and ease of use for each technology option need to be considered carefully.

This section describes typical design-based street lighting systems. The design must be appropriate for the site and should provide the level and uniformity of light suggested in the Indian Standard (BIS, 1981).

Table 3 shows important features to consider when designing and procuring an energy-efficient street lighting system (NYSERDA, 2002).

Street Light Poles

Swage (insertion) type steel tubular poles are used for street lighting and the specification for street lighting poles is explained in Indian Standard (BIS, 1980). The specifications are listed in Table 4.

Mounting Height of Luminaires

One of the important aspects of designing new street lighting systems is to determine the optimum position of the luminaires and the capacity of the light sources.

Table 3: Effective Energy-efficient Street Lighting Systems (NYSERDA, 2002)

Features	Benefits
Proper pole height and spacing	Provides uniform light distribution, which improves appearance for safety and security Meets recommended light levels Minimizes the number of poles, reducing energy and maintenance costs
Proper luminaire aesthetics	Blends in with the surroundings
High lamp efficacy and luminaire efficiency	Minimizes energy cost
Life of the luminaire and other components	Reduces lamp replacement costs
Cost effectiveness	Lowers operating cost
High lumen maintenance	Reduces lamp replacement costs
Good color rendering	Helps object appear more natural and pleasing to the public Allows better recognition of the environment, improves security
Short lamp restrike	Allows the lamp to quickly come back after a power interruption
Proper light distribution	Provides required light on the roads and walkways
Proper cutoff	Provides adequate optical control to minimize light pollution
Minimizing light pollution and glare	Reduces energy use
Automatic shutoff	Saves energy and maintenance costs by turning lamps off when not needed

Table 4: Specifications for Street Lighting Poles (BIS, 1981)

Section	Overall length 11 m + 25 mm (base plate)			Overall length 9.5 m +25 mm (base plate)		
	Outside Dia (mm)	Thickness (mm)	Length (mm)	Outside Dia (mm)	Thickness (mm)	Length (mm)
Bottom section	139.7	4.85	5600	165.1	4.85	5000
Middle section	114.3	4.5	2700	139.7	4.5	2250
Top section	88.9	3.25	2700	114.3	3.65	2250
Planting depth	1800 mm			1800 mm		
Nominal weight of the pole	160 kg			147 kg		
Tolerance on mean weight for bulk supply is 7.5 % Tolerance for single pole weight is 10%						

This can only be done after comparing various options. The optimum mounting height should be chosen by taking into account the light output of the sources, the light distribution of the luminaires, and the geometry of installation. The mounting height should be greater for more powerful lamps, to avoid excessive glare (BIS, 1981). Table 5 shows the mounting heights recommended by the Indian Standard.

Table 5: Mounting Height of Luminaires (BIS, 1981)

Group	Recommended Mounting Height
A	9 to 10 meters
B	7.5 to 9 meters
Others (roads bordered by trees)	Less than 7.5 meters

Spacing

Spacing is the distance, measured along the center line of the road, between successive luminaires in an installation. To preserve longitudinal uniformity, the space-height ratio should generally be greater than 3.

Outreach

Outreach is the horizontal distance between the center of the column and the center of the luminaire and is usually determined for architectural aesthetic considerations (Corporation of Chennai, 2003).

Overhang

Overhang (see Figure 2) is the horizontal distance between the center of a luminaire mounted on a bracket and the adjacent edge of a carriage way. In general, overhang should not exceed one-fourth of the mounting height to avoid reduced visibility of curbs, obstacles, and footpaths (Corporation of Chennai, 2003).

A: Angle of Tilt **Or:** Outreach
H: Mounting Height **S:** Spacing
O: Overhang **W:** Width

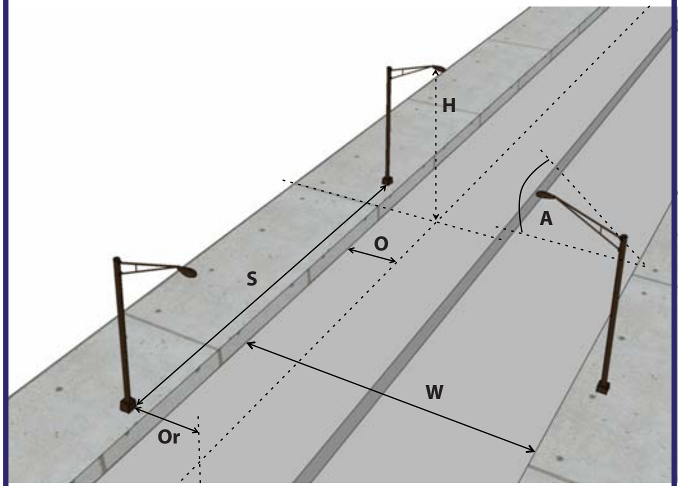


Figure 2: Street Lighting Features (BIS, 1981)

Siting of Luminaires

Four fundamental types of siting arrangements are recognized in street lighting (BIS, 1981). They are:

1. **Single side arrangement,** where all the luminaires are on one side of the road. This is recommended only when the width of the road is equal to or less than the mounting height.
2. **Staggered arrangement,** where the luminaires are placed on either side of the road in a zigzag formation. This is recommended when the road width is 1 to 1.5 times that of the mounting height.
3. **Opposite mounting,** where the luminaires are situated on either side of the road opposite to one another. This is advisable for road widths more than 1.5 times that of the mounting height.
4. **Axial mounting,** where the luminaires are placed along the axis of the road. This is recommended for narrow roads the width of which does not exceed the mounting height.

Recommended Level of Illumination

Recommended levels of illumination for street lighting related to groups A1, A2, B1, and B2 are shown in Table 6 below.

Procurement

It is suggested that municipalities stipulate energy efficiency as a requirement in procurement of street lighting equipment. Municipalities also should incorporate energy efficiency specifications in the procurement tender or bid document/contract, and specify minimum technical specifications such as lumen output, lumen maintenance, and life of lamp, for the lamp as mentioned below (Subodh, 2002).

Lamp

- Wattage
- Luminous flux
- Lumen/Watt
- Average burning life

Luminaires

- Symmetrical light distribution
- Cutoff angle
- Quality of reflector
- Ingress protection

It is also important that the tender give a thorough description of what functional demands should be addressed in a lighting installation to enable selection of the best total solution, in terms of both investment and O&M costs. The life-cycle cost of the products and alternatives must be calculated and presented to provide a holistic view of the project and its future cost.

Lamp and Luminaire Depreciation Factors

In determining the light output for a luminaire, the lighting system designer must consider the luminaire light loss factor. The luminaire light loss factor is a combination of several factors including the Lamp Lumen Depreciation factor and the Lamp Dirt Depreciation factor. The loss factor is applied to the light output of a new luminaire (initial light output) to determine the light output of the luminaire after a fixed period of time. This should be considered during procurement to reduce maintenance cost.

Best Practice in Street Lighting for HPSV

The best practices for HPSV, listed below in Table 7, are based on field measurements for HPSV lamps and can be used as a reference for energy-efficient street lighting (Corporation of Chennai, 2003). However, it is important

Table 6: Recommended Levels of Illumination (BIS, 1981)

Type of Road	Road Characteristics	Average Level of Illumination on Road Surface in Lux	Ratio of Minimum/ Average Illumination	Type of Luminaire Preferred
A-1	Important traffic routes carrying fast traffic	30	0.4	Cutoff
A-2	Main roads carrying mixed traffic like city main roads/streets, arterial roads, throughways	15	0.4	Cutoff
B-1	Secondary roads with considerable traffic like local traffic routes, shopping streets	8	0.3	Cutoff or semi-cutoff
B-2	Secondary roads with light traffic	4	0.3	Cutoff or semi-cutoff

Table 7: Best Practices for HPSV

Lamp		Application	Desired Illumination (Lux)	Mounting height (m)	Width of road (m)	Spacing between poles (m)	Uniformity ratio	Angle of tilt (degree)	Over hang (m)
Watt	Lamp output	Residential	6	6	8	30	0.24	5	0.8
70 w	5800 lumens	Shopping street/road	10	6	6	25	0.38	5	0.8
		Factory road	15	6	6	17	0.53	5	0.8
150 w	14000 lumens	Factory road							
250 w	27000 lumens		30	10	15	30	0.42	15	2.0

to identify the needs and lighting requirements for the particular road since it may have different features.

Dimming Systems

Although the use of dimming systems yields considerable energy savings and represents a financially justified investment, it should be used with caution. The use of dimming systems for street lighting is recommended when the supply voltage exceeds 220 V. This typically occurs between late night and early morning hours when traffic density is significantly reduced.

Common Types of Lamp Dimming Systems

There are presently three types of lamp dimming systems in line voltage: step-level, bi-level, and continuous dimming.

Step-level line voltage dimming circuits work by changing the applied voltage in the street lighting system. A variable voltage low loss transformer is installed at switching points and has timer control and a power factor correcting mechanism.

Bi-level dimming electronically modifies the input voltage into low or high near the lamp by employing electronic low or high frequency switching circuits.

Continuous dimming systems reduce the line voltage continuously through variable step transformers/ variable reactors/wave choppers using electronic circuits.

Dimming High Intensity Discharge Lamps

The exact performance of any HID dimming system or lamp on the system is dependent on the specific dimming

Case Studies

Akola Municipal Corporation, India: T5 Lamps Yield Payback of Less than One Year

In Akola Municipal Corporation (AMC), an Urban Local Body in the state of Maharashtra, more than 11,500 conventional street lights (standard fluorescent, mercury vapor, and sodium vapor) were replaced with efficient, T5 fluorescent tube lamps. The project, which was implemented using an energy savings performance contracting approach, has resulted in energy savings of 2.1 million kWh per year – a 56% reduction in the ULB's energy use for street lighting. These energy savings have resulted in cost savings of about INR 6.4 million per year, and the project paid for itself in only 11 months. The project's success has already led to the implementation of similar projects in Maharashtra and Madhya Pradesh. (ESMAP 2009)

Planned LED Retrofits and Remote Monitoring System Installations in the City of Los Angeles, USA

The City of Los Angeles, California has approved a $57 million retrofit project, involving the replacement of 140,000 city street light fixtures with LED fixtures and the installation of a remote monitoring system to collect and centrally report real-time performance data (including equipment failures) for each fixture outfitted with the technology. The project will be carried out from 2009 to 2013 in five year-long phases:

Year 1 began in July 2009 and encompasses 20,000 fixtures.

Years 2 thru 5 will each encompass 30,000 fixtures.

To take into account the rapid evolution of LED fixtures, for each yearlong project phase the City will reevaluate LED products on the market to determine which products it should install.

Annual maintenance savings (resulting from the long life of LED fixtures) and energy savings are projected to total $10 million, and the corresponding energy savings are project to be 68,640,000 kWh/year. The expected projected payback period is 7 years. (Clinton Climate Initiative 2009)

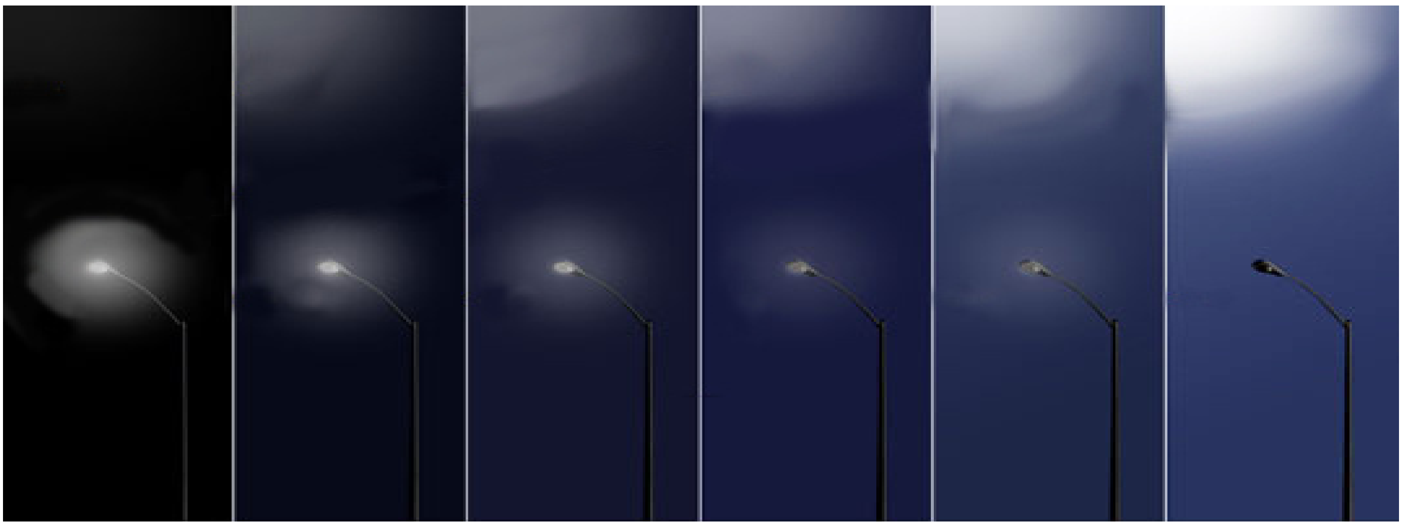
Table 8: Cost information for India – Various EE Street Lighting Technologies

Type of Lamp	Luminous Efficacy	Color Rendering Properties	Lamp Life in Hours	Remarks	Installed Cost [Only Lamp + Luminaire Supply]	Annual Energy Cost	Annual Operating Cost	Total Annualized Cost [Energy Cost + Operating Cost]
	(lm/W)				(INR)	(INR)	(INR)	(INR)
High Pressure Mercury Vapor (MV)	35-65 lm/W	Fair	5,000	High energy use, poor lamp life	465,800	805,920	43,625	849,545
Metal Halide (MH)	70-130 lm/W	Excellent	8,000	High luminous efficacy, poor lamp life	2,449,615	464,954	77,703	542,657
High Pressure Sodium Vapor (HPSV)	50-150 lm/W	Fair	15,000	Energy-efficient, poor color rendering	1,750,286	345,394	10,512	355,906
Low Pressure Sodium Vapor	100-190 lm/W	Very Poor	15,000	Energy-efficient, very poor color rendering	1,370,400	394,200	119,837	514,037
Low Pressure Mercury Fluorescent Tubular Lamp (T12 &T8)	30-90 lm/W	Good	5,000	Poor lamp life, medium energy use, only available in low wattages	390,857	550,629	36,041	586,670
Energy-efficient Fluorescent Tubular Lamp (T5)	100-120 lm/W	Very Good	5,000	High luminous efficacy, only available in low wattages	510,000	474,500	105,120	579,620
Light Emitting Diode (LED)	70-160 lm/W	Good	50,000	High energy savings, low maintenance, long life, no mercury. High investment cost, nascent technology	6,000,000	372,300	0 [incon-sequential]	372,300

Source: *Industry data provided by Electric Lamp and Component Manufacturers' Association (ELCOMA) of India. Assuming 7.5 m. wide, dual carriageway type, 1 km. long road*

Dimming Guidance

- *To avoid reduced lamp life, the dimming of HID lamps should not exceed:*
  - *30% for sodium vapor lamp*
  - *50% for metal halide*
- *Ideal application of dimming includes:*
  - *Non-critical street lights*
  - *Parking garages*
  - *Warehouses and supermarkets*
  - *Security lighting*
- *The use of HPSV/metal halide lamps on dimming systems can result in issues such as color shift and poor lamp performance.*
- *If the supply voltage is less than 220 V after 10 pm, the dimming method may not be suitable for energy efficiency in street lighting because of public safety issues.*



circuitry employed with specific ballasts and lamps. As there are few existing standards for the dimming of HID lighting systems, it is recommended that the user and lighting designer evaluate any new proposed combination of components as a system and test it in the field to ensure that the combined performance of the system is acceptable.

Operation & Maintenance

Energy consumption for street lighting can be reduced by incorporating good maintenance practices such as:

- Replacing defective lamps, accessories, and wires
- Early rectification of cable faults
- Making sure that cables are joined properly
- Regular maintenance of service cabinet/fuse box to avoid loose connections
- Regular cleaning of the luminaire cover to keep it free of dust/dirt and increase light output

A substantial amount of energy savings can also be achieved by installing mechanical/electronic timers and/or daylight sensors for turning street lights on and off.

Metering & Monitoring

Metering is an important component in a street lighting system to properly monitor the performance of the system and energy use, and measure and verify the energy savings in case the system needs to be updated. Defective meters should be replaced immediately to avoid average billing by electricity boards. Advanced technologies like remote monitoring of switching points in street lights can be utilized to record information such as:

- Instant energy consumption
- Trend analysis
- Patterns of energy consumption

These can then be used to identify and analyze reasons for increases or decreases in energy consumption.

Measurement & Verification (M&V)

Energy efficiency street lighting projects cover energy efficiency retrofits, load shifting, load shedding, controls and automation, or combinations of the above. These projects, when implemented properly, achieve reduced energy consumption and result in demand and cost savings. The objective of M&V is to provide a credible, transparent, and replicable process that can be used to quantify and assess the impacts and sustainability of implemented energy-efficiency projects. The basic principle in M&V is comparing the measured electricity consumption and demand before and after implementation to determine the electricity savings. This is demonstrated in the International Performance Measurement & Verification Protocol (IPMVP)'s equation below (Efficiency Valuation Organization, 2007) and illustrated in Figure 3 below.

Electricity Saving: *(Pre-implementation electricity use) – (Post-implementation electricity use) ± Adjustments*

The pre-implementation electricity use conditions are described as the baseline. The baseline represents the electricity use linked to a set of conditions under which the street lighting system was operating prior to

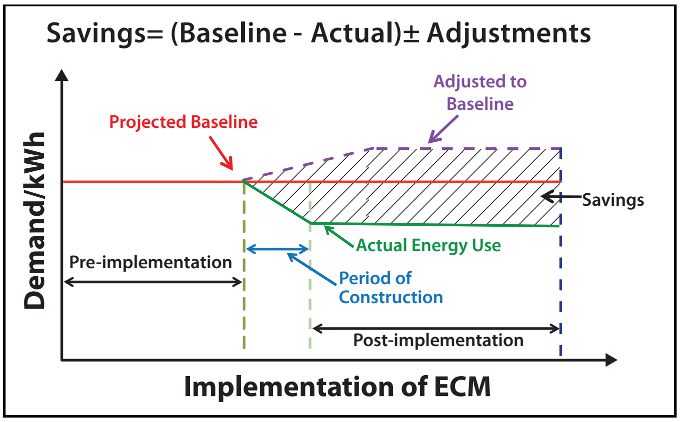


Figure 3: M&V diagram

implementation. These baseline details should include baseline period, baseline energy consumption, and demand data, and all independent variables data coinciding with the energy data (e.g. operating hours, agreed burnout rate, project boundary). If the aforementioned factors remain unchanged, the post-implementation electricity use can be directly compared without any adjustments. However, baseline adjustments are necessary to bring the two time periods under the same set of operational conditions (if any of the pre-implementation conditions changed). Therefore, adjustments are made to restate baseline electricity use under post-implementation conditions. In order to determine the savings, it is essential to establish a post-implementation energy usage scenario if the efficiency intervention had not taken place. The baseline documentation typically requires well-documented audits, surveys, inspections, and/or short-term metering activities. The extent of this information is determined by the measurement boundary chosen for the projects.

M&V Options

M&V of savings can be calculated by following the IPMVP guidelines (Efficiency Valuation Organization, 2007). The IPMVP is the culmination of many years of development of M&V concepts and methodologies through the cooperation of international experts and practitioners. There are two basic methods for calculating savings: the retrofit isolation method and the whole facility method, and each method can be further sub-divided into two sub-options (Options A and B for retrofit isolation method and Options C and D for whole-facility method). Options A, B and C are outlined below (as Option D – Calibrated Simulation, is not suitable for this application).

The appropriate method is selected based on the needs of the utility. If an assessment of a particular retrofit is to be done, then the retrofit isolation method should be used. On the other hand, if the total energy use is to be determined, the whole facility method should be selected. The following section describes the methods and options.

Retrofit Isolation Method

Option A – Key Parameter Measurement

This option only measures the key parameter/s used in the energy computation. It is most applicable when operation conditions are either constant (operating hours can be estimated based on historical patterns of use) or variable (where measurement of operating hours will have to be done on site) and it is possible to assume parameters with a level of certainty that is acceptable to all parties. Savings are typically determined by field measurement of the key performance parameter (s) which define the energy use of the system affected by the energy conservation measure (ECM). The frequency of measurement ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period.

Example: The type of lamp fitting in a lighting installation is changed to a more efficient type while maintaining the same quality of lighting. Energy savings are determined by measuring the energy used by the old and new lighting systems. However the numbers of hours of use may have to be stipulated if the lights are controlled manually. In this case only performance (power drawn by the lighting circuit which was upgraded and in some cases lighting level measurements before and after the project implementation) is measured while operation is stipulated.

kWh (savings) = $(kW_{pre} - kW_{post}) \times hours$

In this case, the energy savings are achieved by reducing the installed lighting demand.

Option B – All Parameter Measurement

This option is used for a single ECM where all factors governing energy use are included. Here, both the performance and the operation should be monitored and measured. Savings are determined by field measurement of the energy use of the system under consideration. The savings are verified by engineering calculations using short-term or continuous measurements, depending on the expected variations in the savings and the length of the reporting period.

Example: In the example above, if automatic lighting controls are included there is no point in stipulating hours of operation, as that would not allow measurement of the impact of the controls. Therefore, total consumption before and after the ECM should be measured and compared.

Examples for routine adjustments include agreed burn out, and switching on and off time. Non-routine adjustments include an increase in the agreed burn out, additional load, change of wattage, non-functioning of timers or controls, and unauthorized tapping of power.

kWh (savings) $= (kW) \times (hrs_{pre} - hrs_{post}) \pm Adjustments$

Here the operating hours are reduced by using a control device on the lighting circuit.

Whole Facility Method

Option C – Whole Facility

This option is used for either a single ECM or multiple ECMs within a whole facility or complete street lighting installation. Savings are determined by measuring energy use at the whole-facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period. Both baseline and reporting period data are needed for the calculation using this option. Energy use should be measured by utility meters for 12 months of the base year and continuously throughout the post-retrofit period. The actual measured consumption in the post-retrofit period is compared with an estimate of what the consumption would have been, in the post-retrofit period, without the ECM. The post-retrofit savings are the difference between the estimated "baseline energy use" in the post-retrofit period and the actual energy measured in the post-retrofit period.

In general, Option C should be used with complex equipment replacement and controls projects where projected savings are relatively large (e.g., at least 20% of the total energy use). It is suggested that Option C be applied in cases where there is a high degree of interaction between installed ECMs or between ECMs and the rest of the facility, or when the isolation and metering of individual ECMs is difficult and costly.

kWh (savings) $= (kW_{pre} \times hrs_{pre}) - (kW_{post} \times hrs_{post}) \pm Adjustments$

This combines efficiency and control improvements.

Example: An entire street lighting system is retrofitted with various ECMs including lighting retrofits (replacements of lights and fixtures), a power conditioning unit, a dimming mechanism, and supervisory control and data acquisition (SCADA) systems. In this case the ECMs may have individual contributions to the total savings and may also interact with other ECMs (e.g., reducing lighting impacts due to controlled voltage supply); the overall effect may therefore be difficult to determine if only individual measures are taken.

Advantages of Effective Energy-efficient Street Lighting

By adopting new and energy-efficient technologies and introducing procurement practices that promote the purchase of these technologies, large energy and cost savings can be achieved. Considering the variable power quality conditions in India, selection of lamps that operate over a wide range of power parameters would significantly reduce the replacement costs of the lamps by reducing the failure rate, although it may entail a high initial investment cost. The efficiency of street lighting can also be significantly improved by selecting appropriate optics for the luminaires as well as ensuring proper mounting height, overhang, and angle of tilt in a street lighting installation. Following these guidelines can enhance visibility and safety, and help reduce electricity consumption and costs, so as to free up resources for other pressing needs, thereby contributing to the improvement of the overall quality of life.

Advantages of Effective Energy-efficient Street Lighting (NYSERDA, 2002)

- ***Enhanced quality of life for people***
- ***Uniformly lit roads and sidewalks***
- ***Reduced glare and improved visibility***
- ***Improved safety and security***
- ***Energy savings***
- ***Capital cost savings***
- ***Maintenance cost savings***
- ***Aesthetically pleasing atmosphere***

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Key Contacts

Dr. Ajay Mathur
Director General
Bureau of Energy Efficiency (BEE)
Email: amathur@beenet.in

Mr. Sandeep Garg
Energy Economist
Bureau of Energy Efficiency (BEE)
Email: sgarg@beenet.in

Dr. Satish Kumar
Chief of Party
USAID ECO-III Project
Email: eco3@irgssa.com

Mr. Shyam Sujan
Secretary General
Electric Lamp and Component Manufacturer's Association of India (ELCOMA)
Email: shyamsujan@rediffmail.com

Dr. Archana Walia
Project Management Specialist (W.Energy)
USAID India
Email: awalia@usaid.gov

Mr. Lekhan Thakkar
Vice President
Gujarat Urban Development Company Ltd. (GUDC)
Email: lekhanthakkar@gmail.com

Mr. Pradeep Kumar
Program Manager
Alliance to Save Energy (ASE)
Email: pkumar@ase.org

Mr. Subodh Shah
Executive Engineer
Vadodara Mahanagar Seva Sadan
Email: subodh1956@gmail.com

USAID ECO-III Project
AADI Building, (Lower Ground Floor)
2 Balbir Saxena Marg, Hauz Khas, New Delhi - 110 016
Tel: +91-11-26853110; Fax: +91-11-26853114
Email: eco3@irgssa.com; Website: www.eco3.org

ALLIANCE TO SAVE ENERGY
Creating an Energy-Efficient World

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