# A RATIONALE FOR THE MANDATORY LIMITATION OF OUTDOOR LIGHTING

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**Summary**

The great value of artificial outdoor lighting has largely obscured the social, ecological and environmental problems resulting from present lighting practice. The exponential growth of outdoor lighting observed in many countries is unsustainable and greatly at odds with the need to reduce greenhouse gas emissions. Artificial skyglow resulting largely from wasteful lighting design and overuse of lighting is increasingly hampering astronomical research and education. Stray light entering bedrooms at night disturbs sleep and contributes to sleepiness and fatigue, known factors in traffic and industrial accidents. Exposure to artificial light at night is also a recognised risk factor for breast cancer and other cancers, and it may be an underlying contributor to widespread obesity. Outdoor lighting does not inhibit crime but increases it. Drastic reductions in outdoor ambient light levels from all sources and in the associated energy use are justified and will require legislation to be achieved.

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# PREFACE

Version1.0 of this document was presented at the *22nd National Australian Convention of Amateur Astronomers* at Mornington, Victoria, Australia, in April 2006. Version 2.1 was presented for the author by Dr Jan Hollan of Brno, Czechia at the *7th European Symposium for the Protection of the Night Sky - Light Pollution and Global Warming* in Bled, Slovenia, 5-6 October 2007.

Version 2.0 had an executive summary added, along with some important new material for guidance of authorities who understand the pressing need to make an early start on reducing greenhouse gas emissions while reducing the cost and improving the quality of outdoor lighting. Version 2.2 included material specifically relating to illuminated advertising signs and was submitted to the Victorian Government's Advisory Committee on Advertising Signs in December 2007.

Subsequent versions include new information on greenhouse gas targets, adverse health effects of light exposure at night, and practical measures for reducing greenhouse gas emissions associated with street lighting.

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# EXECUTIVE SUMMARY

Electric lighting has become ubiquitous since its large-scale commercial introduction in the late 19th century. In many ways it has added to the quality of life by allowing daytime activities to be extended into the natural dark hours. Nonetheless it has become increasingly apparent in recent times that large changes in the natural environment can rarely be made with impunity. This is particularly so in the case of artificial light outdoors at night, where the light flux can often be as much as a million times brighter than the natural value. Small areas might be lit to such levels here and there on the globe without much effect, but the situation has now progressed well beyond this stage in many countries. In short, we now often have far too much light for our own good.

So far, the main barrier to having more and brighter lighting at night has been its capital and operating costs. In deciding to introduce or increase outdoor lighting, the obvious benefits have hitherto been weighed against the money involved. This document indicates that not only has it now become necessary to take a much broader view of the many other kinds of costs associated with artificial outdoor lighting, but it will also become increasingly necessary in future to justify the continuation of existing lighting.

Satellite imagery of Earth at night indicates marked worldwide trends for more and brighter artificial lighting. Town and city lighting is generally becoming brighter and extending further into the surrounding countryside. Ground based measures confirm that total outdoor light flux in many countries is increasing exponentially and is therefore unsustainable. As this quantity is indicative of the growth in greenhouse gas emissions associated with providing this flux, this is a powerful reason for the need to reduce outdoor lighting. In the developed countries that have or should have signed and ratified the Kyoto Protocol, there are two parts to the required reductions: firstly to cut lighting energy use, as a part of all fossil-fuelled energy use, back to the agreed national targets for 2008 to 2012, and then to make timely reductions towards the 2050 global target which is likely to be no more than 40% of the 1990 aggregate, and may have to be smaller again given the rapidity of climate changes already being observed. Furthermore, convergence of per capita energy use to equality between developing and developed nations appears likely to require further large cuts in per capita usage for developed nations.

In Melbourne, the measured growth in artificial skyglow from 1990 to 2007 is about 28 times the maximum growth that could have been expected if lighting energy usage had complied with the Kyoto Protocol maximum growth of 8% generously allowed for Australia. Extrapolating to 2010 indicates that skyglow is then likely to be 3.9 times brighter than in 1990. Indications are that lighting growth elsewhere in Australia has been comparably excessive. Compliance of the lighting sector with the Protocol by 2010 would thus require as much as 97% of the increase in installed lighting since 1990, or its equivalent, to be removed. For other countries with more rational targets (ie reductions rather than growth in greenhouse emissions) under the Protocol, the figure will generally be over 100% if lighting energy usage has increased over 1990 levels. Offsets applicable from increases in use of renewable energy would reduce the excess, as would overall improvements in energy efficacy of lighting; however, resulting improvements in the numbers are likely to be relatively small. Neither the

lighting industry nor the governments involved appear to have grasped the stark reality of the problem.

While anthropogenic greenhouse gas emissions continue at excessive levels, no foreseeable improvements in energy efficacy or renewable energy supplies will allow more than minor mitigation of the problem in the short to medium term. Substantial cuts in energy use are necessary. All lighting must share fully in meeting this burden or some other energy use sector will have to bear additional cuts.

Quite small amounts of stray artificial light entering bedrooms at night can interfere with sleep. This tends to increase industrial and traffic accidents next day. Dim light exposure during sleep can be sufficient to interfere with the body's endocrine system, particularly the melatonin cycle. Melatonin normally helps to protect the body against diseases including breast and other cancers. The World Health Organisation has accepted that shift work increases the risk of cancer in humans, probably through interference with the melatonin cycle.

An epidemiological study published at the end of 2007 has indicated that breast cancer incidence, but not lung cancer incidence, reliably increases with the brightness of outdoor ambient artificial light exposure at night. Bright light exposure in the evening, as with sports lighting and bright public lighting, is known to reduce the amount of circulating melatonin. Few if any present lighting standards mention these adverse effects let alone take any account of them, which is deplorable. Worse, the amount of stray light that can be allowed to fall onto windows of habitable rooms is allowed to be much higher in internationally specified city lighting zones, where other environmental and economic issues have led many people to live in high-rise apartments bathed in this unhealthy bright outdoor ambient light flux at night.

Often when good environmental and health reasons are given to justify reductions in outdoor ambient light flux at night, strident objections are raised on the grounds that crime will increase. While there is no doubt that people do feel safer at night when there is plenty of light, the presence of glare reduces this effect. Furthermore, despite the successful efforts of a few scientists to have their highly biased pro-lighting results publicised and accepted, there is no reliable scientific evidence that lighting reduces actual crime. Indeed, there is reliable evidence that artificial light at night instead tends to increase the actual crime rate- each tenfold increase in light produces a crime rate increase of several percent. Regardless, present lighting standards still tend to specify lighting levels on the basis of perceived or known risk of crime, thereby helping to perpetuate the myth while encouraging crime.

Objections to lighting reductions are also made in the belief that traffic accidents would increase. This ignores the claims of the car window tinting industry that tinting has no effect on the rate of traffic accidents, an argument accepted rather uncritically by politicians in allowing tinting to continue. Statistical evidence indicates that road lighting does reduce accidents at night, but the effect has recently been reevaluated in the UK and found to be considerably smaller than hitherto accepted. Substantial reductions in road lighting specifications have now been instituted there.

Artificial skyglow is becoming an ever more serious hindrance to astronomical research. It also handicaps amateur and educational astronomy and scuttles the near-universal aesthetic pleasure of seeing the pristine night sky. Much artificial skyglow could be avoided by

stopping unused waste light from traveling at or just above the horizontal. Better, by redirecting this light down to the ground where it is needed, the required lamp wattage can be reduced. Wattage can also be reduced by accepting the orange tint of low- or high-pressure sodium lighting instead of the bluish tint of the less electrically efficient mercury vapour lamps or the aesthetically nicer bluish-white output of metal halide discharge lamps. Metal halide lamps are also more expensive to buy, and have the disadvantage that they have greater output of the blue light component that is known to hinder sleep and reduce melatonin. One of the reasons given in favour of metal halide is that its better colour rendering allows potential victims of street crime a better prospect of recognising wrongdoers, but this foolishly ignores the simultaneous and arguably greater advantage for criminals in picking easy victims.

Overall, the case is strong that outdoor light levels are often excessive as a consequence of individual and corporate ignorance, carelessness, selfishness and greed. In the developed nations and many of the developing nations, large reductions in the total ambient outdoor light flux are both necessary and achievable while decreasing actual crime, glare, greenhouse gas emissions and adverse health and ecological effects. Voluntary reductions and self-regulation have certainly not worked in the past, particularly in commercial pursuits such as illumination of outdoor advertising signs and floodlighting of business premises. There appears to be sufficient cause for most if not all illuminated advertising and decorative lighting to be banned. Substantial mandatory reductions in fossil-fueled energy use for lighting with annually reducing caps need to be introduced as a matter of urgency. It is possible for governments to do this in a way that will also save considerable amounts of public and private money while reducing crime, reducing accidents, improving health and reducing environmental and ecological problems such as artificial skyglow.

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# 1. INTRODUCTION

Although the widespread application of artificial lighting has transformed civilisation and enhanced the quality of life, these benefits have been accompanied by the largely hidden costs of substantial ecological and environmental degradation and undesirable social and health consequences.

Light pollution is now a widely accepted term for any unwanted or nuisance (trespass) artificial light that has adverse effects. Many of the problems caused by light pollution could be overcome by using minimal light for the circumstances and confining the light to where it is needed. These are necessary but not sufficient conditions for sustainable, safe and responsible outdoor lighting. Organisations concerned with light pollution have concentrated their efforts largely on campaigns for mandatory shielding of all outdoor light sources to block the direct emission of light at or above the horizontal. Although this is a useful goal and a necessary part of dealing with unwanted artificial skyglow, it is far from sufficient to overcome the total problem, which is much larger. Some light pollution organisations have chosen to work in harmony with the lighting profession in the hope of progress through consensus, but this has come at the cost of little or no action on the major part of the light pollution problem, viz the overuse and accelerating proliferation of outdoor lighting.

New and updated information on light pollution and its adverse effects is presented here. Although some of the evidence available to the writer tends to reflect the situation in Australia, the problems described and their solutions tend to be universal. Permanent solutions will require legally enforced national and regional maxima on the amount of outdoor artificial light, capped at well below present values. The increasingly urgent need to reduce greenhouse gas emissions (GGEs) would appear to justify restrictive caps on energy used to produce outdoor lighting, reducing over time in step with internationally agreed reductions in total GGEs on a national basis.

# 2. BENEFITS OF OUTDOOR LIGHTING

Outdoor artificial lighting provides many benefits:

- It generally improves visibility at night.
- Improved visibility facilitates mobility and travel in dim or dark conditions.
- Outdoor work and recreation can be continued through the natural dark hours.
- It decreases the fear of crime at night.
- Bright lighting helps attract customers to shops, and gives an impression of prosperity.
- Road lighting reduces traffic accidents at night.[1]
- Extensive use of electric light at night helps to raise the base (night) load on the electricity supply system, thereby facilitating performance improvement of fossil-fueled power stations in the system (an economic and greenhouse gas issue).

[1] But the vehicle window tinting industry has been successful in convincing politicians that reducing the amount of light reaching the driver's eyes at night has no adverse effects on road safety!

Satellite imagery of Earth at night indicates marked worldwide trends for more and brighter artificial lighting (Cinzano, Falchi and Elvidge 2001). City lighting is generally becoming brighter and extending further into the surrounding countryside (eg CPRE 2003). At present, attempts to reduce existing lighting or to restrict new lighting have to be justified against the potential reduction or loss of benefits such as those listed.

This document shows that outdoor lighting also brings with it many substantial disbenefits that have not hitherto been given adequate consideration in deciding where and how much artificial lighting is to be installed and how much spill light is tolerable. Spill light is light emitted by a light source in directions other than towards the area where the light is required. In general, spill light is waste light that has not been used. It is usually avoidable by the use of correctly designed luminaires (light fittings). An unavoidable component of waste light is made up of light after it has usefully illuminated some surface or other.

# 3. ARTIFICIAL SKYGLOW

## 3.1 ENERGY LOSS AND SKYGLOW

The night sky in its pristine state is not completely dark. Some of its light comes from the stars, some from sunlight scattered by space dust in the plane of the solar system, and some from atmospheric gases subject to radiation and particle fluxes mostly from the sun. This is called natural skyglow. In the last century, the night sky above artificially lit areas has become increasingly bright as a result of waste artificial light in the atmosphere being scattered back to Earth by air molecules and suspended particles of the atmospheric aerosol. This brightens the night sky and tends to make faint objects in space harder to see and photograph. This light pollution (or strictly, its outcome) is called artificial skyglow.

Typically, artificial skyglow results from unused and used light traveling at or above the horizontal and coming from outdoor light fittings (luminaires), vehicle lights and traffic lights, from windows, skylights and transilluminated signs, and from illuminated surfaces such as roads, building walls, roofs, bridges, monuments and billboards. Vehicle lights add to the problem. Artificial skyglow tends to be proportional to the total amount of artificial light outdoors, but skyglow above a city (or town) has a ‘constant’ of proportionality that can be quite different from that applying to the skyglow caused by that city in the surrounding countryside.

The total artificial light flux emitted by a city tends to be proportional to the product of two quantities, the number of light sources and their mean output of light. Typically, both of these quantities increase over time in individual cities, particularly when the economy is growing. This suggests exponential growth in the total flux. The same result can be reached by considering the typically increasing amount of light in use per person (eg Hänel 2001), coupled with population growth in cities.

Exponential growth in something produced from finite resources is generally unsustainable. Much of the world’s outdoor lighting is powered by electricity generated using fossil fuels. In studying the outdoor lighting situation to guide corrective action, it would be useful to know the relationships between energy consumption for outdoor lighting, the outdoor light flux produced and the resulting amount of artificial skyglow. However, the simple

proportionalities that might exist at a particular time or at a particular place tend to vary with place and time respectively, and it may be difficult to determine some of these variations with the accuracy desirable. Regardless, paucity of information is a weak argument for inaction or delay in dealing decisively with a problem that is as pressing as unsustainable energy use is.

The amount of visible light produced by a unit of electricity consumed by a lamp is called the luminous efficacy, and is usually expressed as lumen/watt. It depends on the type of lamp. For example, the successive replacement of incandescent lamps in streetlights by low pressure sodium lamps after World War 2 produced much more light for the electricity used, but the gains were then reduced with the introduction of mercury vapour, fluorescent and high pressure sodium lamps for reasons other than minimising electricity use.

From 1950 to 1980 in the USA and to 1990 in Germany, the *estimated* outdoor light flux grew at an increasing rate (Hänel 2001), ie exponentially. Even if they exist, *actual* values are difficult to track down for individual countries or regions. One exception is for the town of Osnabrück, for example, where electricity usage for (street?) lighting was approximately constant from 1981 to 1997 while the luminous efficacy and the number of lamps there both increased by about 20% (Hänel 2001). This indicates an exponential increase of about 40% in the outdoor light flux, but this has not been checked by direct measurement (photometry).

Extensive data sets do exist for lighting-related quantities in England from as early as 1711 to the present (Pearson 2003). For example, usage of candle tallow and whale oil for lighting had an overall exponential growth between 1711 and 1900, although there were pronounced fluctuations. Gas for lighting grew more or less exponentially from 1800 to 1900 and thereafter declined as electricity for lighting was in its early stages of exponential growth. This growth continued until about 1970 when it plateaued until the early 1990s, when it rose sharply to recover to its earlier upward trend. Exponential trends in lighting usage are not just a recent phenomenon.

Within the last ten years, metal halide lamps with a white light output have been replacing or supplementing the more efficacious high pressure sodium lamps, which have an orange-white output. This would tend to increase the rate of growth of electrical energy used for lighting more than the rate of growth of outdoor light flux. Again, detailed quantitative data about the actual situation appears to be sparse, which does little credit to the bodies that have profited from this growth.

Towards the end of the 20th century, increasing protests by astronomers led to various generally small reductions in the proportion of upward waste light permitted by national standards for public lighting. Accordingly, artificial skyglow should not have grown quite as fast as total outdoor light flux. Improving air quality would have added to this trend, although industrial growth could be expected to decrease air quality, at least in developing countries. Because short wavelength light tends to be scattered in the atmosphere more than for longer wavelength light, there would have been an opposing trend for atmospheric light scatter to increase during these most recent decades, because white light from metal halide lamps and compact fluorescent lamps replaced or supplemented the orange- or yellow- (ie blue-deficient) tinted light from sodium lamps and incandescent lamps. Therefore in the last two or three decades, as a first approximation the overall amount of skyglow has probably remained more or less proportional to the amount of electricity used for outdoor lighting.

Although street lighting is a major contributor to ambient artificial outdoor light at night and hence to skyglow, account also needs to be taken of additional sources such as vehicle lights, traffic signals and signs, architectural floodlighting, illuminated billboards, and internal light escaping from commercial and residential windows. This was recognised by Oba, Kawakami, Iwata et al. (2005), who found that the respective amounts of light directly emitted above the horizontal from street lighting, from buildings and from illuminated billboards in Tokyo were comparable. It is shown on this basis in Section 3.3 below that if the total light emitted by street and public lighting is L, the total amount of light emitted from all sources in a city centre can be about 1.7 L, and the total upwards waste light (used plus unused) can be about 0.6 L.

These ratios of light flux are also reasonably good approximations to the ratios of energy used to generate the light. Thus the energy cost of producing the skyglow above a city can be about 70% more than the energy costs for street lighting, although some of this total is unavoidable as it includes used waste light. As another indication of the problem, in the Australian state of Victoria the amount of energy lost by *avoidable* light pollution at present is comparable with the total generating capacity of Victoria's operational wind farms. The politicians concerned have been advised of this, but have chosen not to pass the information on to the public.

Artificial skyglow is therefore not trivial either in the waste it represents or in its adverse effects. Most of it is avoidable by modifying lighting practices in line with present knowledge. Reducing or eliminating light pollution will generally save money as well as improving the environment.

## 3.2 GROWTH IN SKYGLOW

The scarcity of quantitative historical data about the total artificial light flux in cities or countries and the corresponding electricity consumption is regrettable. The first global comparison between cities in respect of lighting, population and area[2] seems to be by Isobe and Hamamura (2000), who used satellite measures of upwelling light from cities at night. Monitoring of such light by aircraft or spacecraft could be important in the control of energy use and waste by outdoor lighting. As this upwelling light is also the source of the scattered light that is artificial skyglow, monitoring of skyglow from the ground could provide a relatively inexpensive source of proxy data for ongoing monitoring of energy consumed by all sources of total outdoor lighting.

In natural cloudless dark sky conditions, about 2700 stars are detectable without optical aid in the hemisphere above. Artificial skyglow blots out the fainter stars: in Melbourne (total population 3.5 million, state capital of Victoria), for example, only 2% to 3% of the naturally visible stars per hemisphere can now be seen from the middle suburbs,[3] and it can even be lower than 1% when viewing from the city centre. Given the relationships between the

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[2] The writer was able to find crime rate data for many of the US and English cities as well. Brighter cities tend to have reliably higher crime rates (Clark 2003).

[3] An indication of how much worse skyglow could become in Australian cities is given by the writer's casual observations in the last ten years of the number of stars visible unaided in moonless and cloudless night skies above London (none), Los Angeles (none, but Jupiter seen), Cairo (6) and Kuala Lumpur (6 with 2 oktas of cloud).

number of stars visible or the threshold stellar magnitude and the background sky luminance,[4] eg Schaefer (1990), the sky luminance can readily be derived from visual observations.

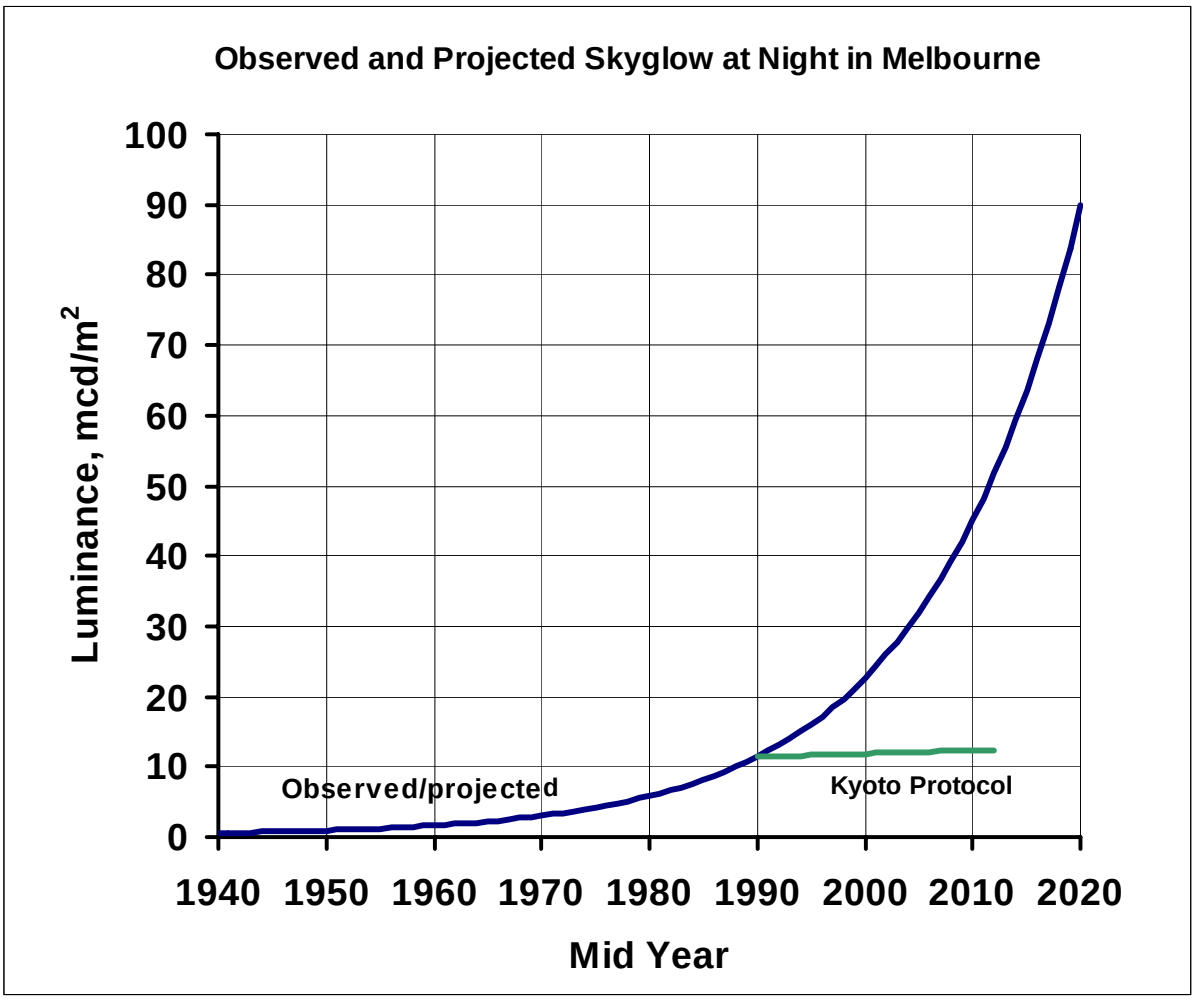


Figure 1. The blue curve is based on a smooth exponential fit to direct and scaled measurements and inferred observations of artificial skyglow over Melbourne from 1880 to 2007. It is shown here from 1940 (ignoring the wartime blackout) and extrapolated from 2007 to 2020. Its steady growth rate is 7.08% pa. The green curve shows the skyglow that would have occurred if lighting energy use had been restricted to the internationally agreed maximum growth in GGEs for Australia according to the Kyoto Protocol, starting from the blue curve value in the Protocol base year of 1990. The actual growth at 2010 is heading to be about 38 times the generous growth (8%, equivalent to about 0.4% pa) allowed for Australia in the Protocol.

The sky luminance can also be observed directly with a precision photometer or with the much simpler and more affordable Unihedron Sky Quality Meter (SQM, http://unihedron.com/) that has become available in recent years. The SQM indicates total

[4] Brightness is a perceptual quantity. Its psychophysical correlates are intensity for a point source or luminance for a surface.

skyglow in the units convenient for astronomers, stellar magnitudes per square arc second. Readings can readily be converted to the SI unit of luminance, candela per square metre ($cd/m^2$) or its convenient submultiple, $mcd/m^2$. The SQM website has a converter.

Curves like that in Figure 1 are valuable as evidence to support the imposition of lighting caps and other corrective actions in connection with environmental requirements. The starting point in generating such a curve is preferably the value of natural skyglow before the introduction of electric light, in 1880, say. At least two more points are needed for curve fitting, preferably well separated, and the more the better to overcome the uncertainty caused by night to night variations. It is important to try to include some values derived from star visibility decades ago. Subtract the known luminance of the natural clear moonless night sky (about 0.28 $mcd/m^2$, but it varies with the solar cycle) from each data point to get the artificial contribution and fit an exponential curve using a computer spreadsheet. Add 0.28 $mcd/m^2$ to the curve heights to get total skyglow. The resultant curve is only indicative of the underlying trend and ignores fluctuations from events such as economic depressions and wars, but the typical alarming growth of recent decades will be well shown.

Figure 2. Melbourne's skyglow in 1990 as seen from Eltham, 20 km from the city centre, at midnight with the moon below the horizon. Photograph by Dr T. J. Richards, Woodridge Observatory, Victoria, Australia.

From Figure 1, the artificial component of Melbourne's skyglow appears to have doubled about every ten years, an increase of about 100% per decade or 7.08% pa. This can be compared with the exponential growth rates of 7% to 10% per annum in skyglow observed in Italy, ie 97% to 159% increase per decade (Cinzano 2002a), 6% pa or an increase of 72% per

decade derived as typical for the USA by Cinzano (2002b), and 3% pa (34% increase per decade) in the UK (Clark 2003). Actual growth rates will fluctuate over time and depend on location, of course, but the smooth exponential approximation provides a good and conservative basis for comparison.

Figure 2 shows what Melbourne's light pollution looked like in 1990 on an occasion when the enormous amount of upwelling used and unused waste light was rendered starkly visible by a layer of high cirrus cloud. The situation was obviously bad in 1990. As Figure 1 indicates, the skyglow is about three times as bright now. Its horizontal extent has also increased in that time.

## 3.3 DEALING WITH ARTIFICIAL SKYGLOW

This analysis is an adaptation of that in Clark (2003). The purpose is to indicate how much reduction in skyglow is possible by reducing various contributing sources measured by Oba el al. (2005). The total output light flux in lumens from streetlights and other public lighting luminaires is L; from vehicle lights, V; from transilluminated or floodlit signs and surfaces, A (for advertising); and internal light escaping from building windows, doorways and skylights, W.

The proportion of total light output of a streetlight that is unused, viz the upward waste light ratio (UWLR), is zero for full cutoff types,[5] and typically 15% for semi cutoff types, 25% for mercury vapour 'flower pots', and more than 50% for pole-top globes and circular wall packs. Assume for this example that UWLR for streetlights and other public lighting is 0.15, and that the same factor applies to vehicle lights. The UWLR for the remaining sources (advertising signs and windows) can reasonably be 0.5. Following Oba et al., the direct upward waste fluxes are set equal:

$$0.15\ L = 0.5\ A = 0.5\ W.$$

Thus, A = 0.3 L and W = 0.3 L. . This is appropriate for a city centre with many signs and lots of tall buildings having many windows. For suburban locations and country towns A and W would be relatively smaller. For completeness, vehicle lighting in the city centre is estimated by V = 0.1 L. The total ambient outdoor light flux T is given by

$$T = L + A + W + V.$$

In this city centre case,

$$T = (1 + 0.3 + 0.3 + 0.1)\ L, \text{ ie } 1.7\ L.$$

The total direct upward flux $T_{DU}$ from these sources is

$$T_{DU} = 0.15\ L + 0.5\ A + 0.5\ W + 0.15\ V,$$

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[5] Lamps shielded *and installed* so that no geometrically direct rays from the face of the luminaire are emitted above the horizontal are called 'fully shielded' or 'full cutoff' (or sometimes 'aeroscreens', perpetuating the outdated belief that they are confined to the vicinity of airfields). Some countries specify such types by limiting the horizontal intensity in any azimuth to no more than (integer) 1 candela (cd) per 1000 lumen (1 klm) of the total output flux. The Illuminating Engineering Society of North American (IESNA) specifies an additional requirement for full cutoff luminaires: the light intensity is not to exceed 100 cd/klm at 80 degrees above the nadir (vertical down direction) in any azimuth. The practical effect of this is to limit glare at horizontal distances beyond about five times the mounting height.

$$= (0.15 + 0.15 + 0.15 + 0.015), \text{ ie } 0.465\ L.$$

The total flux reflected upward from the built environment $T_{RU}$ is the total downwards flux multiplied by the effective reflectance of the terrain, $R_T$:

$$T_{RU} = (0.85\ L + 0.5\ A + 0.5\ W + 0.85\ V)\ R_T,$$
$$= (0.85 + 0.15 + 0.15 + 0.085)\ L\ R_T, \text{ ie } 1.235\ L\ R_T.$$

The total upward flux is

$$T_U = T_{DU} + T_{RU}$$
$$= (0.465 + 1.235\ R_T)\ L.$$

But the total flux emitted by all sources, T, is 1.7 L. Therefore the fraction of total source flux that is directed upward, the Upward Fraction is

$$UF = T_U / T = 0.2735 + 0.7264\ R_T.$$

As a check, UF = 1 when $R_T = 1$. This indicates, correctly, that with perfectly reflecting terrain all source flux would eventually travel in directions at or above the horizontal.

A typical effective value for $R_T$ in a city is about 0.1 if an arbitrary allowance is made for multiple reflections and light trapping by buildings. This indicates that 34.6% of the total light flux will end up in the sky and outer space. Of the Upward Fraction in this example, 0.274/0.346 or 79.2% consists of light directly radiated above the horizontal from all light sources including floodlit surfaces, ie light that does not usually reach the eyes of viewers, and is therefore unused light waste. The remainder of the Upward Fraction can be considered as used light waste. This is consistent with the impression that the light seen in city views from aircraft at night mostly comes directly from luminaires, unshielded lamps, sports lighting, undraped windows and brightly lit signs and surfaces rather than from illuminated roads, paths, fences, walls and vegetation.

If all direct upward unused waste light from road and pedestrian lighting were absorbed by a hypothetical instant installation of full cutoff shields, the first term in $T_{DU}$ would become zero and the total flux T = 1.55 L, with L kept at its original value to facilitate comparison. Then $T_U = 0.4385\ L$ instead of 0.5885 L, a reduction of 25.5%. Note that this is a one-time improvement. If skyglow at the example city is increasing by say 7% a year, it would take just over three years for the skyglow reduction from introduction of full cutoff street lighting to be nullified.

In the case of a ‘dormitory suburb’ late at night with just street and path lighting on and producing 15% upward waste, instant full shielding of street and path lights would reduce skyglow by 64%. For a whole metropolis given instant full shielding on its street and path lights, the reduction in skyglow would thus be somewhere between 25.5% and 64%, probably closer to the former and likely to delay the overall growth of skyglow for maybe only five years. These examples are not overly sensitive to the choice of values such as the terrain reflectance (Clark 2003), but greater reflectance values would reduce the relative impact of full shielding.

The foregoing analysis suggests that the present strategy of the International Dark Sky Association (IDA) is nonoptimal. It has been copied by many smaller groups with similar goals. Much of the IDA effort in the twenty years of its existence has gone into trying to achieve zero upward waste light from outdoor luminaires, and it is still far from attaining that even in the US where its influence is greatest. Compared with the skyglow reduction from introducing full shielding on streetlights, at least in city centres there would be a 12% greater

skyglow reduction by stopping all sign illumination instead, or by having blinds used at night on all external windows of internally lit rooms. It is recognised that pursuing the luminaire shielding issue might have greater political or educational payoff, however, as well as having a larger useful effect in suburban and rural areas.

The IDA's remaining effort has gone into other worthwhile areas such as trying to keep illuminance maxima down to sensible values in lighting standards, having commercial lighting switched off after business hours, and writing a model lighting ordinance. It has attempted to do such things, with some success, by convincing the lighting industry to cooperate. Some IDA office bearers and members are lighting professionals with a genuine interest in 'sky friendly' lighting. The downside of this strategy is that the IDA tends to avoid discussing or doing anything that could have the potential to alienate the lighting industry.

Since the IDA has been in existence, it has made some progress in the introduction of laws and standards to reduce upwards spill from outdoor luminaires. But while this has been happening, the overall trend in most countries has been the installation of more and brighter outdoor lighting; bigger city buildings with more glass walls, brighter internal lighting and no blinds; and more billboards, often bigger and brighter. In general, the total ambient outdoor artificial light flux generated by individual nations has been growing exponentially, often much faster than growth in the corresponding national gross domestic product, and both the extent and brightness of the accompanying artificial skyglow have been growing more or less in step with the total light flux.

Whatever gains have been made by IDA action in reducing upwards spill from outdoor lighting over the last two decades have been utterly swamped in that time by the increased skyglow resulting from growth in total outdoor light flux. What is desperately needed to solve the long-term problem of skyglow is to stop the total growth of lighting and turn it into a decline; absolutely nothing else will do. The IDA has made its choice: naturally it doesn't wish to be identified as the cause of a shrinking lighting industry because it could hardly expect cooperation from the industry in such circumstances. Unfortunately, the choice virtually guarantees the accelerating growth of outdoor light flux and artificial skyglow towards all-night artificial twilight, contrary to the IDA's *raison d'être*, to protect the night sky.

A permanent solution to the skyglow problem must involve reducing caps on total outdoor light flux or energy use for lighting or both. Self-regulation does not work any better than would voluntary speed limits on the roads, for example; it has to be the law and it has to be enforced. Restrictions on direct light emission above the horizontal, mandatory use of blinds to prevent the escape of internal light at night through residential, commercial and industrial windows, and severe restrictions on illumination of outdoor signs would all help to bring useful but one-time improvements, but their impacts in reducing skyglow and the accompanying energy wastage will become relatively smaller as time goes on unless the overall growth is reversed as well.

## 3.4 SPATIAL DISTRIBUTION OF SKYGLOW

By using a Sky Quality Meter in conjunction with a Global Positioning System (GPS) receiver, it is now relatively easy to measure the distribution of skyglow across a city or region in little more than the time it takes to travel through the required distance. The major

precaution necessary is to take the measurements from a position in which any potentially interfering artificial light source is close to the horizon and out of the sensor field or is at least shielded by a light pole, tree trunk or low building. Unlit sports fields are often the best available choice in populated areas as they also provide clearance from trees that tend to reach into the sensor field.

Figure 3 was made with data from an SQM and a GPS in conjunction with a road map. Three of the measurements made are not shown: they were taken at or near intensely lit intersections or car parks and are clearly outliers with luminances of up to 120 mcd/m$^2$. The most distant reading was made a month earlier, and was close to the natural value.

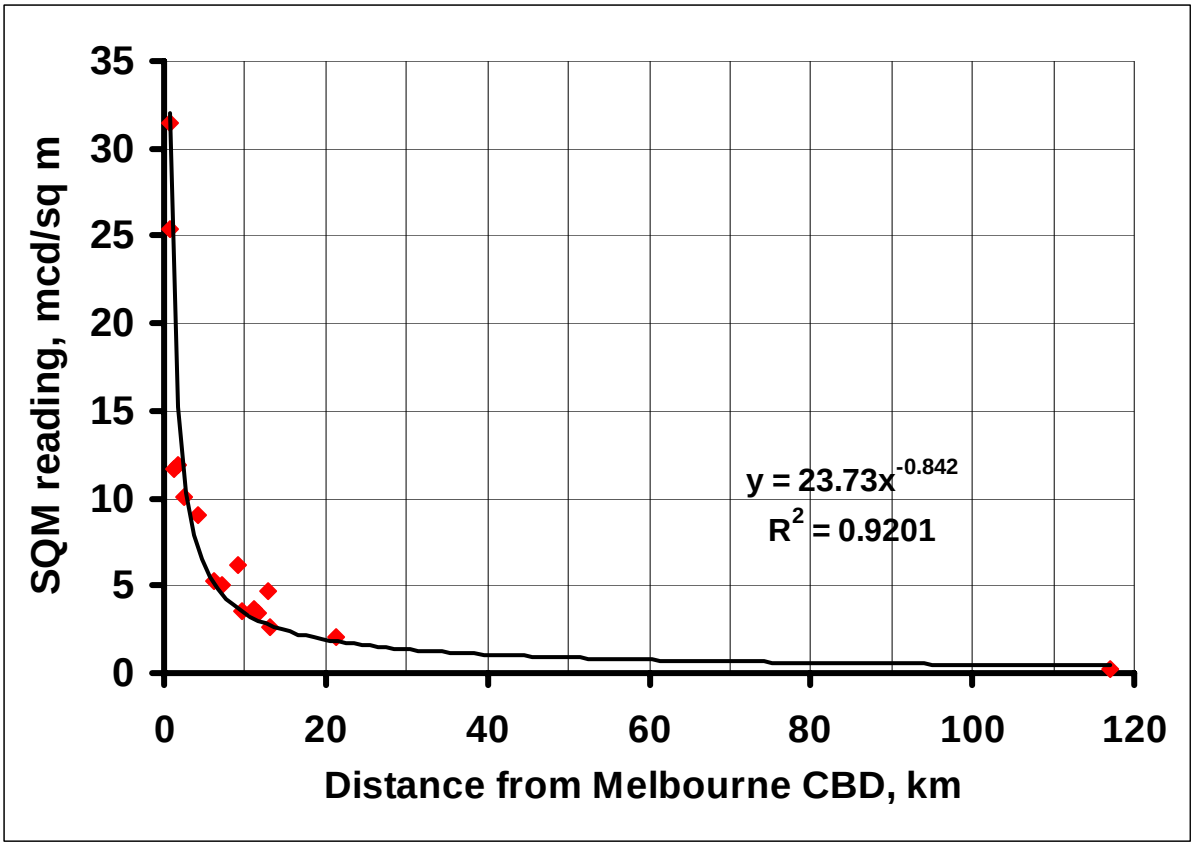


Figure 3. Total skyglow as a function of distance from the Melbourne Central Business District on 22 February 2006 with a moonless clear sky. The most distant reading was at the Leon Mow Dark Sky Site of the ASV near Heathcote in central Victoria. 17, 19 and 21 stellar magnitudes per square arc second convert logarithmically to 17.1, 2.71 and 0.43 mcd/m$^2$ respectively.

The sharpness of the peak suggests that much of the skyglow originates within or near the CBD, where there are many buildings and structures floodlit from below, despite a longstanding city lighting strategy that deprecates the practice. The decorative twin columns of the Bolte Bridge alone have 90 kW of near vertically aimed narrow-beam floodlighting. Crime-prone areas of the city have repeatedly been given more and brighter lighting but crime continues to grow there, consistent with the findings in Clark (2002, 2003). Large brilliantly

lit billboards have been constructed near and even as an integral part of city tollways. Most of the lighting excesses are for commercial purposes.

Baddiley and Webster (2007) is a new analysis of the physical processes that give rise to artificial skyglow. It is based on distribution diagrams for different luminaire and lamp types and known scattering properties of the atmosphere in numerical modelling. The findings include the following:

> "Therefore any direct light travelling just above the horizontal is a major contributor to skyglow. Ground reflected light is typically a factor of 10 lower depending on ground reflectivity."
> "Light going straight up from towns has less effect on skyglow on clear nights in rural locations, than that travelling sideways. This is important as it can be easily prevented by using modern luminaires with well controlled upward light emissions."
> "… minimising light emitted from luminaires at or near the horizontal is of paramount importance."
> "Do we need the light or not?"

The importance of minimising spill light emitted in the few degrees just above the horizontal has been known from practical experience (eg in northern Italy) for at least ten years, but this has been ignored or discounted in revisions of the Australian standards for outdoor lighting. As a consequence, most of the luminaires used in Australia for road and public lighting emit a substantial amount of light in this environmentally damaging range. As road and public lighting is the predominant source of outdoor lighting flux in the middle and outer suburbs of Melbourne, this explains why the curve in Figure 3 has such a long tail of values above the natural skyglow value. It extends well past the outer edge of the outer suburbs, typically 20 to 40 km from the CBD.

## 3.5 Outdoor Lighting and Greenhouse Gas Emissions

Large scale scientific research work fostered and coordinated by the United Nations and national peak science bodies has identified ongoing rapid climate change and global warming as highly likely to be mostly or fully caused by anthropogenic release of certain gases into the atmosphere. The gases include carbon dioxide, methane and others that transmit solar energy largely unhindered and tend to absorb the longer wavelength radiation emitted by Earth's surface. The main effects are to raise Earth's surface and atmospheric temperatures, ie the 'greenhouse effect', and to increase the variations that occur in weather. Another effect of rising atmospheric content of carbon dioxide is to increase the acidity of the oceans. The dynamics of this situation are that even if all fossil-fuel burning ceased overnight, ocean acidity will continue to grow for the next century, with the consequent likely extinction of many oceanic species.

One of the early outcomes of the UN action on climate change was the UN Framework Convention on Climate Change (FCCC). Signatory nations, which included Australia, accepted a legally binding obligation to reduce GGEs. The Kyoto protocol of 1997 set 1990 as the base year for assessing reductions, the end of the reductions period as 2008 and the reductions for most nations as five percent. At the last minute, Australia perversely negotiated an 8% emissions *increase* by 2010. This was reluctantly accepted by the other developed nations to avoid outright failure of the Protocol. Later, the Australian Government, along with the US Government, refused to ratify the Protocol.

Australia and the USA (along with some small rich nations) are the world's largest emitters of greenhouse gases on a per capita (ie per person) basis. The US and Australia have claimed that compliance with the Protocol would place them at an economic disadvantage compared with developing nations such as India and China. On the other hand, the developing nations maintain that the bulk of greenhouse gases in the atmosphere at present were put there by the developed nations over the past two centuries, and the Protocol falls well short of redressing this imbalance.

Concern in the Australian population about the Australian government's failure to ratify the Kyoto Protocol was a factor in the change of government that took place in late 2007. Australia ratified the Protocol soon after.

Some of the developing nations have proposed that equitability would require GGE limits to be set on a per capita basis. Compliance with this is called 'convergence' (eg Garnaut 2008, pp 30-33). It would place severe burdens on the developed nations, but anything short of this hardly seems likely to provide a satisfactory long-term result. A current compromise being proposed by some developed nations is to work towards equal greenhouse intensities for nations, greenhouse intensity being the total emissions per nation divided by the nation's gross domestic product. This could be counterproductive by tending to retard the development of developing nations, an outcome that most nations appear unlikely to accept.

The world body that oversees and interprets global science on the greenhouse effect is the Intergovernmental Panel on Climate Change (IPCC). It is a joint panel of the World Meteorological Organization and the United Nations Environmental Program. The IPCC issues reports on its assessment of the observed extent of climate change, its predicted change and effects, its cause, and global measures required to reduce the effect of the identified anthropogenic contribution to climate change. Its Assessment Reports are becoming gloomier about the severity of the likely impacts of predicted effects of climate change and the consequent need for large early reductions in the global emission of greenhouse gases attributable to human activity.

The Fourth Assessment Report of the IPCC, *Climate Change 2007*, represents six years of research by over 2500 scientists from more than 130 countries. Nearly all of the IPCC scientist members support the finding that decisive global action is required to reverse the rate of growth in the emission of greenhouse gases into the atmosphere. Delayed or incomplete action will greatly decrease Earth's capacity to support the human population and the diversity of all other living things. IPCC (2007) concluded that global GGEs will probably need to be reduced to 40% or less of 1990 levels by 2050 to avoid severe adverse effects from climate change. It does not appear likely that the supply of energy from renewable and nuclear fission sources and gains from increased energy efficacy will be sufficient to achieve this while total energy demand continues to increase. In other words, energy usage will have to be reduced.

Regardless of how reductions in GGEs are to be achieved, it is apparent that the desire of developing nations for equality in per capita access to energy and therefore their continued growth will place the developed nations under heavy pressure to reduce their own target GGEs to maybe 20% or less of 1990 levels by 2050, with intermediate binding targets of 25% to 40% reductions by 2020 as well. Even greater reductions may be justified, for example to

just 10% by 2050, given the accelerating rate of climate change effects observed since the cutoff date for observations considered by the IPCC (Garnaut 2008).

Delay in starting the reduction process would increase the size of reductions required in later years. Reductions need to be implemented as soon as practicable with the early reductions being arithmetically the largest. At present it appears that the required reductions in fossil fuel burning can only be fully achieved by mandatory cuts to fossil fuel energy supply. For aviation in particular, there are few prospects for replacing fossil fuels. Therefore cuts in fossil fuel usage will need to be greater in other energy use sectors, such as land and sea transport, manufacturing, agriculture, commercial and residential. Outdoor lighting is part of each of these sectors. There would appear to be virtually no prospect that outdoor lighting will be allowed to continue on its present rapid expansion untouched.

Naturally, energy companies see such potential actions as a threat to their income and profits. Some have worked hard to try to discredit the science of the greenhouse effect and its consequences, and to have governments accept that economic prosperity would be severely reduced if the proposed substantial reductions in emissions were put into effect. The Australian and US governments in particular have followed these lines in attempts to avoid binding targets for emissions reductions, but the recent change of government in Australia has led to a more constructive Australian policy in which the economy is now seen as dependent on the environment rather than specifying what environmental concessions can be made.

The economic issues still have to be faced. The UK Government's independent Stern Review of the economics of climate change (Stern 2006) indicates that the economic costs of substantial emissions reduction are likely to be smaller than were previously assumed, and much smaller than the eventual costs of doing nothing. The regional situation is being examined in Australia and an interim report has been issued by Garnaut (2008). It notes that the latest information about climate change is more pessimistic and stresses the need for drastic cuts in GGEs in Australia by 2020 and 2050 while the nation takes advantage of its natural resources to develop renewable energy sources and to assist other countries in the region to limit their GGEs also. Energy use sectors such as lighting are not mentioned specifically but that level of detail is intended for inclusion in Garnaut's final report, which is due for completion in late 2008. The present version does address the issue of compliance, noting that mandatory measures will be required rather than voluntary. For the same reason, 'mandatory limitations' has been part of the title of this document since its first issue in early 2006.

One of the ploys still being made by vested interests to argue for a reduced role of greenhouse gases in climate change is to point to evidence of climate forcing by solar activity or some other external action. Actually the apparent solar forcing is the opposite of what these interests have been claiming insofar as the indices of solar activity have been reducing while global warming has been increasing in recent years, while other possibilities are tentative at best (Lockwood and Fröhlich 2007). Regardless, as an example suppose that 10% of the observed rate of climate change is from some external cause such as solar forcing, cosmic rays, meteor infalls or whatever. For nations with the highest per capita GGEs, instead of needing to reduce emissions by say 80% of 1990 levels, it would have to be about 89% reduction in emissions for the total of greenhouse effect plus unchanged solar effect to reach the required 20% of the total 1990 base year emissions. The conclusion is that it would be prudent for the developed nations to aim for emission reductions even larger than those

currently contemplated to allow for any unknown but probably small external forcing effect. Garnaut (2008, p 8) reached a comparable conclusion more succinctly.

Another tactic that tends to prolong the status quo for the lighting sector and some other energy use sectors in Australia and some other countries is to introduce the notion that the base year can be set at several years later than 1990 with little effect. This may have face validity in the US, where GGEs in 1996 were apparently comparable with those in 1990. It is not true in the case of Australia, as shown in Figure 4. Despite this, the federal and state governments of Australia have encouraged local councils to manage GGEs in their municipalities according to the Cities for Climate Protection (CCP) program. The base year generally chosen for CCP assessments is 1996.

This has given rise to a widely circulated notion that compliance with the Kyoto Protocol can be achieved by similar limits on emissions relative to 1996 levels. But for Melbourne's outdoor lighting as indicated in Figure 1, it is apparent that this 1996 CCP baseline is about 50% higher than the 1990 Kyoto baseline, more than the increase for all GGEs over this period shown in Figure 4. Local councils often use this 1996 base year in claiming voluntary compliance with the Kyoto Protocol when their growth in emissions, which typically has a large public lighting component, is actually a blowout.[6]

Although figures for annual increases in local government expenditure on lighting do not appear to be readily available, municipal council representatives at recent sustainable public lighting seminars in Victoria have described increases of up to 5% pa after allowing for inflation. The actual growth exceeds this, presumably because of lighting growth in new subdivisions in the outer suburbs and growth in non-council lighting such as commercial lighting and outdoor advertising signs. In Australia, any annual rate over 0.4% accelerates the gap between the Kyoto Protocol and what is actually happening. The proverbial *Fool's Paradise* comes to mind.

Light pollution reports by amateur astronomers in other large Australian cities and in rural areas indicate rapid growth much like that in Melbourne, so it appears that CCP procedures have unwittingly fostered unsustainable growth in energy use for public lighting in Australia.

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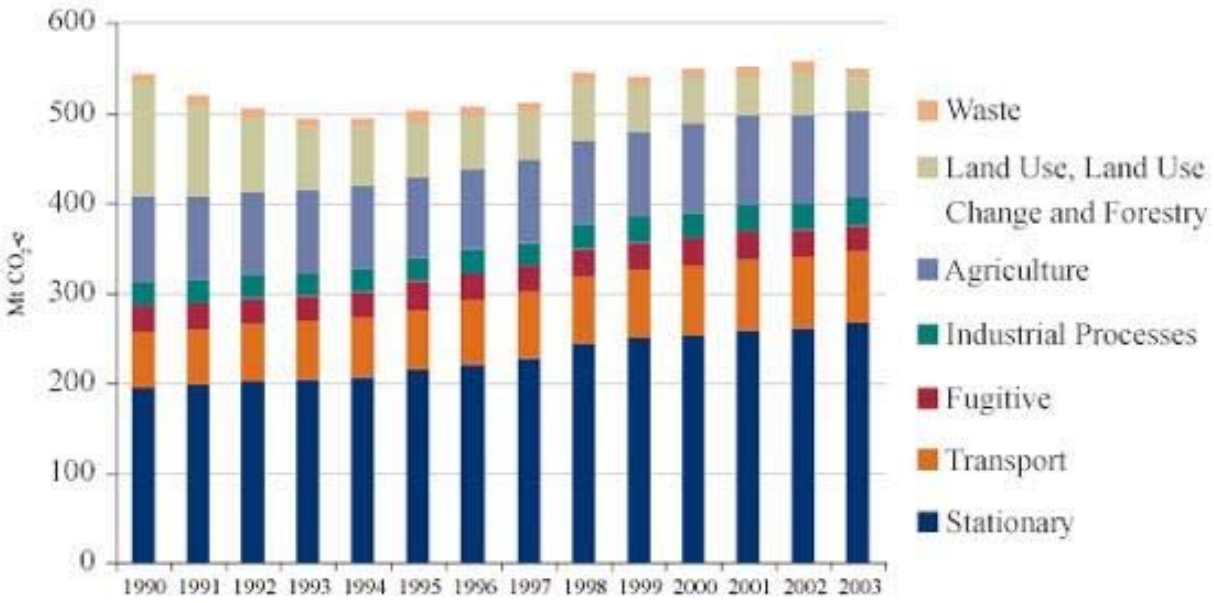
[6] The author has alerted the Australian and Victorian governments to this problem on several occasions since 2004, but no serious response has been received and no attempt to correct the problem has been apparent. For example, when an earlier version of this document was sent to the Victorian Minister for the Environment one of his staff members responded with a do-nothing reply along the lines of 'thank you for your interest in this aspect of government policy'. Another ministerial staff member said that proposals for reductions in public lighting could not be considered as public amenity would be affected.




Source: Australian Greenhouse Office, 2006, http://www.greenhouse.gov.au/inventory/

Figure 4. Greenhouse gas emissions in Australia. The Australian stationary energy sector emissions for 1996 are about 18% higher than they were for the Kyoto Protocol base year of 1990. Compare this with the observed photometric increase in Melbourne's artificial skyglow in this period, 50%, an approximate indication of the corresponding increase in energy consumption then for outdoor lighting.

Using country sites for dark sky observations is a current work-around for city-dwelling amateur and professional astronomers in developed nations. But artificial skyglow from cities is now detectable over hundreds of kilometres away with inexpensive equipment. If the present unsustainable growth in outdoor lighting continues over the coming decades, many existing dark sky sites will be afflicted by skyglow as bright as that of suburbs at present. New observing sites will need to be established at locations several times further away from cities than the present distances. Amateurs would face unpalatable or prohibitive increases in travel time and costs. Given that amateurs are contributing more than ever before to knowledge of the universe, hampering their scientific endeavours will come at a cost to humanity.

For the professional observatories at Siding Spring (a sparsely populated inland part of the Australian state of New South Wales), the spread in skyglow from Sydney (the state capital) and nearer population centres poses an increasingly severe threat. Unless the growth in outdoor ambient light flux at night is stopped or reversed, in due course Siding Spring will inevitably experience the unacceptably bright skyglow levels that currently afflict Mount Stromlo Observatory near Canberra in the Australian Capital Territory. This kind of threat to professional astronomy appears to be happening in many other countries also. The costs of forced relocation to more remote sites would be worrying for the various national governments and organisations involved. Transport of goods and personnel could be increasingly discouraged by GGE controls. Again the handicapping of astronomical research needs to be considered seriously and avoided by decisive action to curb unnecessary outdoor

light flux from all sources, given that astronomy is one of the prime wellsprings of scientific and technological progress.

## 3.6 ILLUMINATED ADVERTISING SIGNS

The amount of light pollution produced by conventional illuminated advertising signs is a much greater part of the total available light output of the lamps used than is the case for best practice road and path lighting. Despite this, planning authorities generally appear to be largely unaware or unconcerned about the amount of light pollution generated by advertising signs and the adverse consequences. It is helpful to be aware of the kinds of controls that already apply in many places to other aspects of illuminated advertising signs and the reasons for these controls, so that trends to more, bigger and brighter signs might best be dealt with in the context of minimising the overall adverse environmental, health and social costs of total outdoor light flux. It is a common mistake to try to deal with such issues in isolation.

### 3.6.1 The rise of advertising signs

Outdoor advertising signs are undeniably an important part of current commercial and retail practice. After they were first introduced some long ago it must have became evident that the attention-getting power of such signs depended on their perceived angular subtense and contrast with the visual surround as well as on the subject matter and its presentation. Diminishing returns helped to set limits on the physical size and number of signs on premises. Off-premises signs allowed increased exposure to potential customers, but similar constraints applied.

The situation changed late in the 19$^{th}$ century when it became economically possible to illuminate signs at night. If the mean luminance of a sign is $L_S$ and of the background is $L_B$, the contrast is $(L_S - L_B) / L_B$. For a painted white sign of reflectance say 85% against a painted black background with reflectance about 5%, both similarly illuminated by daylight, the contrast can be as high as about (85 - 5) / 5, ie 16. For an illuminated sign at night seen against an unlit background or the night sky, contrasts in the thousands or more are readily achievable. This might be fine for the advertiser but a nuisance or worse for viewers trying to see something else in the visual scene. The advertising industry has become adept at trying to control what consumers look at and see, and light is one of their most important tools.

In an era when streets were dimly lit, if lit at all, presumably there were few objections to the light spill from illuminated signs. In due course, the sizes and brightness of advertising signs tended to increase and their numbers grew, along with the numbers of objectors concerned about aesthetics by day and sleep disturbance by night. The potential of advertising signs as a road safety hazard has also become an increasingly important issue. For understanding the problems of advertising signs in the environmental, health and social contexts of excessive artificial light at night, it is convenient here to draw largely on extensive records of US experience. Where documents cited use the term ‘billboard’, it is used here as synonymous with ‘advertising sign’.

### 3.6.2 US experience with billboards

In the USA, the federal Highway Beautification Act (HBA) of 1965 effectively banned billboards along federally funded roads. The Act stipulates that states that do not adhere to

the Act are subject to penalties equal to ten percent of their federal highway funds. Unfortunately, sections of the outdoor advertising industry have vigorously exploited legal loopholes that actually force the retention of offending billboards (Scenic America 2007a).

Organisations such as Scenic America have been formed by objectors to seek legislation that re-establishes the original intent of the HBA, which was primarily concerned with the protection of aesthetic values in scenery. Opposing them is the Outdoor Advertising Association of America, an industry peak body that lobbies against billboard restrictions in general. At present, the following US states have legislation banning the construction of new billboards (Scenic America 2007b):

Vermont - Removed all billboards in 1970s
Hawaii - Removed all billboards in 1920s
Maine - Removed all billboards in 1970s and early 1980s
Alaska - State referendum passed in 1998 prohibits billboards

The US total of cities and communities prohibiting the construction of new billboards is estimated to be at least 1500 (Scenic America 2007b).

Industry lobbying was successful in 1978 in having Congress make concessions to allow on-premises business signs in view of federally funded highways. Since then, electronic displays have been introduced in which individual pixels can be varied in colour and intensity to change the displayed sign or image. Digital electronic techniques allow this to be done so quickly that video sequences can be displayed. (These 'giant video screens' are now in use for action replays at major sporting events.) Although the HBA clearly prohibits moving and flashing displays on billboards, the 1978 concession has been exploited by the industry in setting up networks of on-premises digital (or electronic) billboards (DBBs or EBBs) within sight of federally funded highways. This appears to be part of a strategy to have off-premises digital signs also exempted from the provisions of the HBA (Scenic America 2007c).

An Internet search for existing restrictions on outdoor advertising signs indicated that a large number of states, regions, towns etc in the US and elsewhere have their own ordinances including illumination bans and limits. There seems to be little commonality in the wording, usually no reasons are given to support the restrictions imposed, and there appears to be little if any concern about upward waste light or energy consumption. One of many controls on signs in New Zealand, for example, is summarised here for interest (Transit New Zealand 2007): it is a national measure to limit adverse effects of advertising signs on road safety and the environment in the vicinity of state highways. A broad definition of advertising sign or device is provided. Illumination and reflectorisation of signs is not permitted: this would appear to rule out electronic displays that emit light, but would allow electronic displays such as liquid crystal displays illuminated by ambient light. Sign surfaces must be parallel to the road boundary, which limits the ability of drivers to see them other than with substantial foreshortening. A reason is given for this restriction: it is intended to prevent back reflections from headlights, however.

### 3.6.3 Driver distraction by conventional and electronic billboards

This matter has been under discussion over many years. Only a few recent studies are presented here to indicate current opinions.

The hazard of distraction of drivers is a key issue arising from a review of studies of dynamic advertising signs (SRF 2007). The review mentions a 1999 survey by the (US) National Alliance of Highway Beautification Agencies: as many as 36 US states had banned some kinds of signs or imposed restrictions on them. Dynamic signs, ie those with flashing or moving displays, were often mentioned. The VicRoads *Ten Point Road Safety Checklist* that arose from the Parliament of Victoria 2006 Report of the Road Safety Committee on the Inquiry into Driver Distraction is reproduced in full, along with additional operational requirements for electronic advertising message signs, eg such signs must not display animated or moving images, or flashing or intermittent lights, and must not be visible from a freeway.

SRF (2007) also includes the views of four subject matter experts: Harder considered EBBs a driver distraction threat; Davis stated that a causal relationship between EBBs and accidents had not yet been established but should be possible with careful attention to the scientific issues; Robinson said that multi-image signs should not change more often than every 6.2 s on fast roads [VicRoads specifies 30 s] and the requirements for EBBs might need to be different; while Wachtel believed that it is neither feasible nor necessary to demonstrate a causal relationship between EBBs and road safety (or its reduction). Instead, he thought that scientific understanding was already adequate for development of operational guidelines and ordinances.

The US Federal Highway Administration remains concerned about the driver distraction hazard posed by billboards. To try to counter this, the Outdoor Advertising Association of America recently released two reports in which it was claimed that conventional and electronic outdoor advertising signs did not have an adverse effect on road safety. An independent peer review (Wachtel 2007) of these reports indicated that they were seriously biased and otherwise flawed scientifically. Wachtel concluded that rigorous scientific studies have yet to be done on this matter, so that any liberalisation of existing restrictions on billboards visible to drivers would be ill-advised at present.

The first purpose of an advertising sign is to attract attention. In so doing, it distracts the viewer from attending to other visual tasks. If the viewer is driving, distraction is likely to increase the attendant hazard. If the advertising sign is a type in which the display can be changed quickly to increase its attention-getting function, it would appear to be of greater potential hazard to drivers. Whatever road safety restrictions might be found applicable to conventional advertising signs, there appears to be a strong prima facie case that restrictions applying to variable signs, especially video-capable displays, should be more stringent unless rigorous peer-reviewed scientific work specifically shows otherwise. Although the two papers criticised by Wachtel (2007) were too poor scientifically to allow much to be drawn in the way of reliable conclusions, some of the observational data collected indicated trends for glances at electronic signs to be substantially longer and therefore more hazardous than for glances at conventional signs.

### 3.6.4 Other road safety issues of illuminated signs

Glare from a bright light source at night can cause discomfort and reduce visibility of other objects in the field of view. It is generally recognised that glare, particularly from oncoming headlights, has contributed to road accidents at night. It is technically complex to define glare quantitatively for limiting the allowable adverse effect on road users, but examples do exist. At the other end of the scale is the sort of qualitative limitation used in the Victorian road

regulations, which prohibits lights so bright that a driver is prevented from having a clear view ahead. This regulation has apparently not been enforced to any extent in Victoria for decades, and there are many other places in other states and countries with similar problems. Car dealership floodlighting and 'security' lighting, often misaimed and overbright, are common sources of avoidable glare. In the context of this section, so are the floodlights used to illuminate advertising signs, as well as illuminated or transilluminated sign surfaces themselves.

Of course, a level of glare that might be acceptable for a driver with excellent vision may be severely disabling temporarily for a driver with marginally acceptable vision. The presence on the windshield of one or more of aftermarket tinting, volatiles from the car upholstery, condensation, and raindrops and dirt, in combination with marginal vision forms a set of worst cases that should be used to argue for no high-glare fixed lighting of any kind to be visible within a driver's view ahead. Compliance with this condition would require all road and public lighting luminaires to be full cutoff types and advertising sign luminances to be orders of magnitude dimmer than is generally the case at present, as in the following table from Clark (2003), based then on a draft of the Czech Clean Air Act.

**TABLE 1. Maximum Luminance and Intensity for Illuminated Billboards and Signs**

| Maximum Area, $m^2$ | Mean Luminance, $cd/m^2$ | Total Intensity, cd |
|---|---|---|
| 1 | 100 | 100 |
| 3 | 48 | 145 |
| 10 | 21 | 215 |
| 30 | 10 | 310 |
| 100 | 4 | 460 |
| 300 | 2 | 660 |
| 1000 | 1 | 1000 |

Governments with a determination to reduce the contribution of glare to road accident causation should consider adopting an approach like that in the table, which reduces the luminance of signs as they are made larger. But the need to deal decisively with the anthropogenic component of climate change could well see the end of illuminated signs anyway.

### 3.6.5 Obtrusive effects of advertising sign illumination

A Google search produced 26 900 hits for 'billboards light pollution'. Many of the web pages listed were concerned with the unpleasantness and even misery caused to residents when large brightly lit billboards are set up nearby, and possible ways of trying to deal with the problem. Affected residents often find that they are at a financial and hence legal disadvantage in trying to stop a proposed sign and virtually powerless in practice to obtain amelioration of the nuisance once the sign is in operation. Properties receiving rent for signs typically find their property value increased but residential property values in the vicinity tend to fall because of loss of amenity.

Unresolved complaints about obtrusive lighting was one of the reasons why Standards Australia decided in the 1990s to issue a standard to limit the obtrusive effects of outdoor lighting other than road and public lighting. The outdoor advertising industry in Australia was represented on the drafting committee and sought provisions that it would not find onerous. Eventually the industry opted for self-regulation while insisting successfully that the standard would specifically exempt illuminated advertising signs from any need for compliance. Sports lighting interests managed to have TV broadcast standard lighting likewise exempted. The resultant Australian Standard AS 4282-1997, *Control of the obtrusive effects of outdoor lighting*, thus does not apply to many of the most obtrusive lighting sources in modern cities. Self-regulation in the case of advertising signs effectively means that the sole or primary constraint on the brightness of sign lighting is economic.

Planning authorities in Australia seldom raise the matter let alone insist that non-exempt outdoor lighting should comply with AS 4282-1997. Primarily this is because of the lack of state government leadership in leaving obtrusive lighting to individual local councils to deal with. Avoiding the need for compliance with an applicable Australian Standard is contrary to federal and state government policy. However, it avoids arguments about differences of conditions arising from differences of interpretation across municipal boundaries, so change in this area has been difficult to bring about. In general, illuminated signs, along with floodlit buildings, structures and sports grounds, continue to set the pace in Australia and elsewhere for lack of concern about degradation of the night environment and indifference to the rights of local residents.

In the many years since its introduction, initially as an interim standard from 1995 to 1997, AS 4282 has apparently not helped in Australian attempts to curb the upward 'ratcheting' of sign brightness and size that passes for competition in the outdoor advertising industry. It is now clearer than ever that lighting, size and placement of advertising signs need to be under stringent mandatory control to prevent or limit the occurrence of glare and deep shadows, environmental and social problems and excessive upward spill light.

Given that company logos and the tops and sides of company buildings are often floodlit or transilluminated as a form of advertising, there is no reason why such lighting should be regarded as exempt from any controls that should be applicable to floodlighting of advertising signs, again if such floodlighting is to be permitted at all in future. To cope with this prospect, Table 1 would need to be extended by at least four rows, with continuity in the three geometrical series.

Illuminated advertising signs and other lit displays in more-or-less vertical planes have a propensity to put half of their available light output more or less uselessly above the horizontal. This effect is not easy to eliminate in any of the three most common types: floodlit opaque billboards, 'neon' or 'electric' signs and internally lit translucent signs. Typically about half of the light reflected or transmitted/emitted by conventional signs travels in directions above the horizontal, lighting up the sky. The peak output of light is generally normal to the plane of the sign and therefore in or close to the horizontal direction, almost the worst possible in terms of the resulting light pollution and artificial skyglow.

Much more effort needs to go into making the light output directional, aimed at where the sign is allowed to be seen from, while still complying with luminance restrictions such as those suggested above.

Another major problem with advertising floodlighting relates to whether the floodlighting is located above and shining down or below and shining up, or both. The lighting and advertising industries prefer low placement because of easier access for lamp replacement, lack of shadows on the sign surface in sunlight, and easier confinement of downwards light spill. But that arrangement puts the maximum amount of light above the horizontal, and has therefore been rigorously opposed by the dark sky movement.

### 3.6.6 Banning illumination of advertising signs

Lighting roads and paths with full cutoff fittings has the virtue that associated GGEs and the amount of light pollution are close to the lowest values possible for a given lamp type and the amount of light utilised. Conventional illuminated signs are highly inefficient by comparison in terms of the amounts of wasted light and the GGEs associated with that waste.

The effect of banning illumination of advertising signs can be quantified by extending the analysis of Section 3.3 above. The quantity A becomes zero, so the total ambient outdoor light flux T′ is given by

$$T' = L + W + V, \text{ with } W = 0.3\ L \text{ and } V = 0.1\ L \text{ as before.}$$

For the city centre,

$$T' = (1 + 0.3 + 0.1)\ L, \text{ ie } 1.4\ L \text{ or } 1.4\ T / 1.7.$$

The total direct upward flux $T'_{DU}$ from these sources is

$$T'_{DU} = 0.15\ L + 0.5\ W + 0.15\ V, \text{ ie } 0.315\ L.$$

The total downwards flux reflected by the terrain is

$$T'_{RU} = (0.85\ L + 0.5\ W + 0.85\ V)\ R_{T,} \text{ ie } 0.109\ L.$$

The total upward flux is

$$T'_{U} = T'_{DU} + T'_{RU}, \text{ ie } 0.424\ L, \text{ or } 0.72\ T_{U}.$$

So, removing all illumination from advertising signs would reduce city light pollution by 28%, and reduce the outdoor ambient light flux by 1- 1.4 / 1.7, ie 18%.

The results here and in Section 3.3 above depend on the numerous assumptions made, but they are relatively insensitive to variations in the initial conditions. They should be regarded as indicative of the results that could be expected if the various processes described were modeled numerically using input data from actual measurements. What this analysis does indicate reliably, as has long been known intuitively, that advertising sign illumination causes a disproportionate amount of light pollution. Putting it another way, cessation or reduction of advertising sign illumination would lead to a considerably larger aggregate reduction in light pollution than the resulting aggregate reduction in ambient outdoor light flux.

The results of the analyses would be no less valid if they described the changes that would be introduced by the operation of a lighting curfew. Progressively earlier curfews could be a way of phasing out illumination of existing signs during adjustment to the reducing income. Exemptions or concessions might be claimed for some signs, eg on-premises signs while the company was genuinely open for business on that specific site at night, but fully offsetting additional reductions in other sign illumination would need to be in place and subject to audit.

The importance of these results in relation to GGEs is that GGEs from the generation of electricity used to produce outdoor light flux typically represent about a tenth of all GGEs

resulting from all electricity usage. The actual fraction is often poorly documented if known at all for individual countries, but there are reliable comparisons between many countries in terms of waste upward light flux measured from space. On a per capita basis, these values are generally much higher in developed countries than in developing or undeveloped countries (Clark 2003). Changing the amount of light being used in a particular country results in a more-or-less proportionate change in the GGEs associated with that lighting.

# 4. JUSTIFYING CHANGES IN LIGHTING PRACTICE

If the present exponential growth of outdoor lighting in Australia continues, it is clear that the skyglow threat to astronomy will continue to worsen unhindered in the longer term even if light spill control measures such as those proposed by lighting organisations (eg ILE 2000) or the International Dark Sky Association (IDA 2007) are introduced and high levels of compliance are achieved. National and regional reducing caps on outdoor ambient light flux are required instead or preferably as well, but the astronomical problem by itself seems unlikely to be accepted by governments as sufficient reason for imposing drastic restrictions. But other reasons do exist to justify mandatory control of the amount of outdoor ambient artificial light at night, as distinct from control of the energy used or the greenhouse gases emitted to produce that light. The most compelling of these relate to health, wellbeing and the maintenance of biodiversity.

## 4.1 SLEEP DISTURBANCE AND ACCIDENTS

Quite small amounts of light at night can delay and disturb sleep.[7] The Australian Standard AS 4282-1997, *Control of the obtrusive effects of outdoor lighting*, sets the maximum outdoor artificial illuminance allowed in the plane of windows of habitable rooms at between 1 and 25 lux depending on the circumstances, despite citing a German study in which complaints began when the external illuminance at windows at night was as small as 0.1 lux. AS 4282 includes a denial that its window illuminance limits merely perpetuate existing lighting practices, but this denial seems hollow. Extensive questionnaire surveys in Czechia by Forejt, Skočovský, Skotnica and Hollan (2004) indicated that for sleep to be undisturbed by lighting, the maximum external illuminance in the plane of bedroom windows should not exceed 0.1 lux, regardless of where the dwelling is located.[8] Hollan (2007) showed that this proposed requirement can be achieved even when the road surface adjacent to the window is artificially lit to as much as 2 lux, which is about eight times brighter than the brightest moonlight. Full cutoff streetlighting will often be essential for the requirement to be achieved.

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[7] Note that the normal incidence illuminance produced by the full moon never exceeds 0.27 lux. Generally it does not exceed 0.2 lux in the vertical plane. For individual windows that can receive moonlight, values approaching 0.2 lux occur only for a few hours each month at most.

[8] It is international practice for lighting standards to allow greater illumination of windows in city lighting zones defined by the International Commission on Illumination (CIE) but this practice now appears to be so hazardous that a complete rethink of lighting practices is required. Health and safety should not be compromised by allowing excessive light for any reason in the middle and inner zones of cities, particularly as present excesses are largely a product of careless, ignorant, wasteful and selfish lighting practices and indicative of glare.

Ad hoc observations by the writer and colleagues[9] using Sky Quality Meters in several suburban bedrooms, together with occupants' reports of spill light effects on sleep, definitely support this 0.1 lux maximum. Note that the typical high quality conventional light meters have increments of 0.1 lux at their most sensitive settings, so setting the limit at 0.2 lux instead could allow the actual exposure to be as much as 0.3 lux in practice, which would appear to be quite inadvisable.

Sleep loss and sleep disturbance degrade wellbeing (Dement and Vaughan 1999) and can substantially increase the risk of road and industrial accidents in which daytime sleepiness and fatigue are factors (Dawson and Reid 1997; Stutts, Wilkins and Vaughn 1999; Williamson and Feyer 2000). In a new study of drivers involved in motor vehicle crashes, 16 (55%) of a consecutive sample of 29 drivers had at least one sleep-related risk factor. This suggests that the number of sleep-related collisions is four times greater than those identified using current criteria of the Australian Transport Safety Bureau (Crummy, Cameron, Swann et al. 2007).

Phipps-Nelson, Redman, Schlangen and Rajaratnam (2007) compared three kinds of nocturnal light exposure, all from 11-30 pm to 5-30 am, as a means of improving performance in a simulated truck night driving task. The exposures were <1.5 lux of 460 nm light, <1.5 lux of 640 nm light, and <1 lux of white light. Performance on a Psychomotor Vigilance Task was enhanced and delta and theta EEG activity was suppressed by the blue light exposure but not by other exposures. Therefore less than 1.5 lux of blue light is sufficient to keep humans alert during normal sleep time. Although not the purpose of the experiment, this means that such an exposure would hinder normal sleep at night, a key result in setting limits for stray light in bedrooms at night.

The use of heavy drapes or even blackout blinds to block excessive stray artificial light is undesirable as such barriers also block the important beneficial waking effect of morning light for the bulk of the population (Forejt and Hollan 2004; Forejt, Skočovský, Skotnica and Hollan 2004). If governments are as serious as they claim to be about reducing road and industrial accidents, they should act to limit total artificial illuminance to 0.1 lux at windows of habitable rooms, regardless of rural, suburban or urban location. Current international guidelines on this matter are in urgent need of correction.

## 4.2 LIGHT AT NIGHT, OBESITY, MELATONIN AND CANCER

Unnatural light exposure at night can have other serious effects on health and wellbeing (Wiley and Formby 2000; Pauley 2004).

Many mammal species exhibit a food craving known to be related to the extended duration of daylight during summer, leading to storage of body fat in preparation for the coming winter famine. Wiley and Formby (2000) suggested that the same mechanism can affect humans who are incompletely adapted to artificial light simulation of year-long summer light durations and not subject to a winter food shortage. This is their explanation of the increasing global incidence of obesity and obesity-related illnesses such as Type 2 diabetes. It is supported by laboratory trials (Spiegel, Tasali, Penev and Van Cauter 2004) in which human sleep curtailment resulted in decreased levels of the satiety hormone leptin, which is a

[9] Particularly Geoff Dudley, Deputy Director of the Outdoor Lighting Improvement Section of the ASV.

response to a caloric shortage, and elevated levels of the hunger hormone ghrelin, which stimulates appetite. Speigel et al. noted that mean sleep duration in the US population had decreased by one to two hours over the past forty years. Spiegel et al. did not refer to the Wiley and Formby book.

A meta-analysis of cross-sectional studies from around the world indicated a doubled risk of obesity among short sleepers in children, adolescents and adults (Cappucio, Taggart, Kandala et al. 2007).

Like most living things, the human body produces the hormone-like substance melatonin in dark conditions at night. Light exposure at night, especially in the small hours, can interfere with this process. In particularly careful laboratory experiments, as little as 0.4 photopic lux of blue light has been found to cause a half-saturation nocturnal melatonin response in humans (Glickman, Levin and Brainard 2002). In ordinary domestic situations, light exposures would be more likely to be polychromatic white rather than near-monochromatic blue. Exposures of less than a hundred lux of white light can have an appreciable effect on melatonin, depending on the deep-blue spectral component of the light.[10] Evening exposure to 500 to 1500 lux for 1 to 2 hours is typical for sporting teams and many of the spectators in high-level competition and televised games at night. Such exposures can suppress melatonin levels by 40 to 60% (NAPBC 1997).

Dijk and Lockley (2002) reviewed the literature to portray the relationships between light exposure and the circadian rhythm[11] in humans. Light exposure during habitual sleeping time, especially in the first half, tends to delay the cycle, while bright exposure during the morning tends to advance it. Interference with the circadian rhythm by external factors leads to sleep disruptions and complaints. Gooley, Brainard, Rajaratnam et al. (2007) found that melatonin suppression and circadian phase delays in 46 humans were linearly related and dependent on photon density and wavelength of light irradiation for 6.5 hours during the early biological night. Blue light ($\lambda$ 460 nm) had about twice the effect of green light ($\lambda$ 555 nm).

In interpreting the literature, there is a need to know whether the experiments reported refer to times at night when the eyes were open or shut. Naturally much more light is required to reach the retinal receptors if the eyes are shut, so the argument might be that stray light is of less consequence when the person is asleep. But it is common experience to be awake at night and there is no guarantee that eyes will always be shut at the time. The need is to determine safe levels of stray light at night in the worst case, which is having eyes open and exposed. The safe level will be lower in this case than in the cases of eyes covered or closed.

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[10] But researchers funded by the lighting industry found that 18 lux from blue light-emitting diodes was more effective at suppressing melatonin than 450 lux from mercury vapor lamps. Instead of finding out why their thresholds were well over an order of magnitude higher than those reported by others, they concluded that white light used in buildings was much less effective at suppressing melatonin than was previously thought (LRC 2004)! Revell and Skene (2008) showed that a white lamp that had the same amount of blue light as a blue lamp actually produced a greater suppression of melatonin. The use of blue-rich white lights such as mercury vapour lamps, cool-white fluorescents and CFLs, and metal halide lamps is thus more hazardous at night than the use of incandescent bulbs and warm white discharge lamps.

[11] 'Circadian' means 'about 24-hourly'. Circadian variables include body core temperature, plasma melatonin and wakefulness.

This is the value that will eventually determine the maximum allowable amount of stray light in cities.

It has been known since the 1980s that melatonin is one of the body's most powerful agents for retarding the growth of breast cancer and other cancers, and many laboratory and field studies have shown reliable positive connections between breast cancer incidence and light exposure at night (eg Davis, Mirick and Stevens 2001; Schernhammer and Hankinson 2005; Blask, Brainard, Dauchy et al. 2005). The authors of the latter paper concluded (italics added):

> "Thus, strategies to preserve the integrity of the circadian melatonin signal (i.e., *avoidance of bright light at night*, intelligent lighting design, circadian-timed physiologic melatonin supplementation) coupled with modifications in nocturnal dietary fat intake may offer a unique approach to the prevention of breast cancer, and perhaps other melatonin-sensitive cancers, in our increasingly 24-hour society".

On the basis of "limited evidence in humans for the carcinogenicity of shift-work that involves nightwork", and "sufficient evidence in experimental animals for the carcinogenicity of light during the daily dark period (biological night)", in December 2007 the International Agency for Research on Cancer Monograph Working Group of the World Health Organisation concluded that "shift-work that involves circadian disruption is probably carcinogenic to humans" (Straif, Baan, Grosse, Secretan, El Ghissassi, Bouvard, Altieri, Benbrahim-Tallaa and Cogliano 2007). WHO statements like this are necessarily conservative.

Since the WHO finding was announced, Kloog, Haim, Stevens, Barchana and Portnov (2008) have described a thorough study in which a positive association was found between night light intensity measured by satellite and breast cancer rates in females in 147 towns in Israel. Multiple regression analyses indicated that breast cancer rates were higher in the more brightly lit areas, which tended to be densely populated areas with high living standards. Conversely, abnormally low cancer incidence rates were found in low-income areas where outdoor and indoor artificial illumination tends to be dimmer than elsewhere for economic reasons. As a test of the method, female lung cancer incidence was also examined, the idea being that there was no known reason why this type of cancer would be affected to any extent by differences in amounts of light at night in different areas. Indeed, no reliable correlations were found for lung cancer incidence and amount of light at night. After adjusting for several variables such as ethnic makeup available on a population level, a strong positive association was revealed between light at night and breast cancer rate ($p < 0.05$) and this association strengthened ($p < 0.01$) when only statistically significant factors were filtered out by stepwise regression analysis. The average artificial light exposure level was 9.1 times brighter than the minimum measured and corresponded to a female breast cancer rate 37% higher. From the dimmest to brightest areas, the rate was 73% higher.

Kloog et al. concluded that their study further strengthens previous findings of correlations between artificial light exposure at night and breast cancer in females. It is also consistent with the known impact of illumination on melatonin production and secretion by the pineal gland and the involvement of a variety of hormones in the development of breast cancer.

In round figures, the size of the effect observed by Kloog et al. can be summarised as 'ten times the ambient artificial light at night corresponds to a forty percent greater rate of breast cancer'.

In the May 2006 issue of the prestigious journal *Cancer Causes and Control*, there were nine papers and reviews dealing with the relationship of breast cancer and other cancers to light exposure at night. All agreed that light exposure at night appears to be a substantial risk factor for breast cancer. Blue light of about 460 nm is particularly potent in affecting melanopsin, the primary circadian photopigment in rodents and primates (Glickman, Levin and Brainard 2002). Therefore the present tendency of replacing sodium lamps (which have a blue-deficient output) with metal halide lamps (which have a bluish-white output) appears to be ill-advised, quite apart from the substantial loss of energy efficacy associated with the change.

For televised sporting events under sports lighting at night, the illuminance on the playing area is in the order of 1500 lux. Present sports lighting practice is to have the crowd lit to about a third of the levels on the playing area. These levels are certainly high enough to reduce melatonin levels substantially during a two-hour exposure. For this reason and others given elsewhere in this paper, including excessive light spill and GGEs, sports lighting at night may well have to be greatly reduced if not phased out altogether.

In a recent thorough review of the topic, Navara and Nelson (2007) stated that urban light pollution and shiftwork contribute to the increasing prevalence of exposure of humans to artificial light at night, resulting in significant social, ecological, behavioral, and health consequences that are only now becoming apparent. Light pollution has demonstrated effects on daily human life. Interruptions in normal circadian light cycles disrupt normal melatonin rhythms and lead to widespread repercussions in humans and many other species. The effects both on individuals and populations are of concern, and need to be understood in order to deal most effectively with the cause, too much artificial light at night.

## 4.3 Outdoor Lighting and Crime

The effect of lighting changes on crime has typically been studied with field trials. This method involves comparison of crime counts in test and control areas before and after an increase is made in the lighting of the test area. By the early 1990s, scientific reviews in the USA and UK had established that outdoor lighting was ineffectual for crime prevention. However, common belief in the efficacy of lighting against crime seems to have persisted, perhaps because of confusion with the commonly experienced beneficial effect of lighting in reducing the fear of crime.

Since the mid 1990s, the resurgence of interest in the UK in the use of lighting for crime prevention can be traced primarily to one researcher's PhD results from field trials in two UK towns, eg Painter and Farrington (1997; 1999a). The published papers exhibit strong bias (Clark 2002) towards the belief that lighting prevents crime. To check the extent of this bias in the conduct and original analysis of the trials in Painter's thesis, the writer applied to see the thesis. A librarian at the University of Cambridge advised that access would be refused at least until 2008. Additional papers by Painter and Farrington (1999b; 2001) made no attempt

to correct or explain the apparent bias (supposing that this was even possible),[12] and they build on results that appear to be seriously erroneous. The lead researcher was supported by lighting industry grants but this is not acknowledged in all of the papers. None of the papers mention the lead researcher's personal relationship with a lighting industrialist, admitted later according to the reporter in a news magazine article (Private Eye 2005). These apparent omissions are not an indication of bias but if the circumstances are true, the papers should have followed scientific method by advising readers of the situation because it would appear to imply a substantial potential for conflict of interest and consequent unwitting bias.

Farrington and Welsh (2002) did a meta-analysis of published lighting and crime trials including the two mentioned. The results indicated that lighting increases (not the ab initio installation of lighting) decreased crime by about 20%, an improbably large value (Clark 2002, 2003). Marchant (2004; 2005a, b; 2006a-d) has shown convincingly that all field trials of lighting and crime to date are invalid because their statistical analyses have all ignored the fact that individual criminals often commit multiple crimes. The number of crimes in a test or control area is larger than the usually unknown number of independent crime events that should have been used instead to determine the before-after changes and their statistical significance. Furthermore, most if not all field trials had a test area that was chosen for a lighting upgrade because it had a relatively high level of crime to begin with, and the phenomenon of regression towards the mean biases the results towards a systematic false positive effect of lighting. Meta-analysis does not correct for systematic bias but instead helps to hide its presence in the primary result of the analysis.

Farrington and Welsh (2004, 2006) have tried to defend their work against Marchant's criticisms but their meta-analysis still appears to be invalid for both reasons, viz erroneously high statistical significance of the input data from individual trials and preservation of the pro-lighting systematic bias in the input data. The UK Home Office compounded the problem by refusing to withdraw Farrington and Welsh (2002) and by refusing an offer of Clark (2002, 2003) at no cost for publication in the same Home Office Research Study series.[13]

Morrow and Hutton (2000) reported that installation of more and brighter street lights in Chicago alleys produced a 21% increase in crime relative to a well matched control area. The increase in light flux in the test area was 3.8 times but a smaller increase also took place in the control area so that the differential increase was about 3.4 times. The observed increase rather than a decrease in crime was much to the consternation of the researchers, who should have been disinterested in the sense associated with scientific method. They ignored the most likely interpretation, ie that lighting increased crime, and instead tried to find reasons to

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[12] For instance, one of the treatment areas appears to have been given extra police patrols and crime prevention pep talks attended by the researcher. Crime in the treatment areas in both trials was significantly higher than in the respective control areas to the extent that both trials should have been abandoned at the outset.

[13] It seems contrary to scientific method for a scientific work to be published in a forum that does not accept major scientific criticism of that work for publication. The Home Office also has a duty of care to ensure that government funds are not used counter-productively. At the time of writing, the Home Office was still actively promoting the Farrington and Welsh report as support for the ongoing process of upgrading street lighting throughout England.

explain the result as wrong. They also cut short the statistical analysis. If such an approach were more widely adopted, it would seriously retard the progress of science.

The Morrow and Hutton paper was not included in the Farrington and Welsh meta-analysis. Including it and allowing for some major faults in the other included studies would produce an inconclusive result. But this would be a waste of time because the Morrow and Hutton paper is about yet another field trial with no account of the effect of multiple offences, so it is therefore also invalid according to Marchant's work.

Regardless of the strength of the case that the Farrington and Welsh meta-analysis results are unreliable, lighting professionals continue to use those results as a justification for increasing outdoor lighting according to the known or perceived risk of crime. For instance, the Australian/New Zealand Standard AS/NZS 1158 series for road and pedestrian lighting continues to do exactly this.

In 2004, the UK government had been convinced by sections of the lighting industry to spend £300 million on streetlighting upgrades primarily to reduce crime, and the funding amount has since grown to over £1 billion. Crime in England and Wales fell steadily from a peak in 1995 to a minimum at the end of 2004 and has since risen slightly, but not by an amount of statistical significance (Nicholas, Kershaw and Walker 2007). There is no sign of the decreases that should have taken place according to Farrington and Welsh (2002) but the small rise is in the order of what might be expected according to Clark (2003).

More examples of advocacy of lighting as a crime prevention measure occur in published material of the schools known as *Crime Prevention Through Environmental Design* (CPTED) and *Situational Crime Prevention* (SCP). 'Mixed' (expected and counter productive) results from practical application of increased lighting are explained away by claims that lighting seems to work best when combined with other measures such as better locks and increased police presence. In stark contrast, the Farrington and Welsh meta-analysis includes several trials affected by such substantial confounding factors but Farrington and Welsh ascribed the whole of the observed crime changes to the effect of lighting alone, thereby inflating the supposed benefit!

CEPTED and SCP material also claims that lighting assists in crime deterrence by aiding natural surveillance. This is fine as far as it goes, but the rest of the story is seldom mentioned, viz that lighting simultaneously provides assistance for the commission of crime. Clark (2003) provides statistically reliable epidemiological evidence that the overall net effect of lighting is to assist more than to hinder criminal acts. The effect is in the order of a few percent increase in crime for each factor of ten increase in artificial light flux.

Installation of more and brighter lighting is also counterproductive as an anti-graffiti measure. Even casual observation will readily reveal that graffiti tends to be less common in places that are dark at night, and rare in unlit parts of tunnels.

Clark (2003) makes it quite clear that the effect of imposed darkness at night is to reduce the crime rate, over and above any temporal and spatial displacements of crime. This sets the causal direction in the observed positively correlated growth of lighting and crime. Three months after that document was posted on the Internet, confirmation came on a grand scale in the power failure of August 2003 that affected the northeast part of North America. Despite

some early sensationalised news accounts to the contrary, there were actually no newsworthy increases in crime anywhere, just large decreases. When this became clear in New York City, politicians and police were quick to claim that the reduction there was because of the extra police deployed there and their competence. The claim can now be seen as ludicrous, given the relatively modest statistically reliable effect observed by Klick and Tabarrok (2005): a 50% increase in police presence reduced crime by just 15%.

The reduced crime effects of a lighting reduction or lighting blackout persist even when the loss of lighting lasts for months. For example, in Des Moines, Iowa, 39% of the roadlights rated above 70 watts on main traffic routes were turned off in September 2003 as an economy measure. Reported vandalism, burglary and robbery in the city dropped 3.5% in the first four months of 2004 (Alex and Paluch 2004) after rising 10% in 2002 and dropping 6% in 2003. In the northern Swedish town of Övertorneå and parts of the neighbouring town of Haparanda, a dispute between the local council and its electricity distributor resulted in the streetlighting being switched off for over five months during autumn 2006 and the 2006-7 winter. Since the switchoff, the number of thefts and burglaries halved and there were no traffic accidents that could be attributed to the darkness (SVT 2006; SVD 2007; Cumming 2007). There are many comparable examples, even back in the gaslight era.

There is no doubt at all that people feel safer with more and brighter lighting (Boyce, Eklund, Hamilton and Bruno 2000). It is ironical that more and brighter lighting is now known to be conducive to increased actual crime. At present, there seems to be no way around this problem, although reduced-glare lighting might help a little by optimising the fear-reducing effect. Fortunately, full cutoff lighting advocated to minimise light pollution is also reduced-glare lighting. One of the reasons why sections of the lighting industry do not like full cutoff lighting is that semi cutoff lighting puts more light near the horizontal specifically to light up the faces of potential assailants, unmindful of the evidence that the assailants get even more assistance from being better able to choose their victims by seeing their faces.

Whenever lighting reductions are proposed for environmental reasons, opposing vested interests tend to trumpet the need of lighting for security. The use of the word ‘security’ in this context can now be considered to be ‘spin’, in that it implies both actual safety and feelings of safety, a false combination of opposites insofar as the effects of lighting are concerned.[14] In most cases ‘security lighting’ is an oxymoron, and use of the term in advertisements should now be subject to sanctions under fair trading laws.

Given the invalidity of evidence for a beneficial effect and the clear evidence to the contrary, advocating lighting for crime prevention is like advocating use of a flammable liquid to try to put out a fire. Fundamental changes in lighting practice are now required by the facts- use only the minimum practicable amount of outdoor artificial lighting and thereby keep the crime rate lower than with present lighting practice.

## 4.4 JUSTIFYING OUTDOOR LIGHTING

Outdoor lighting has proliferated greatly since the widespread introduction of electric light in the late 19th century. It has led to many improvements in the quality of life. The lighting

[14] This condemnation does not extend to the use of lights switched on temporarily by intrusion detectors to provide a visible alert.

industry has done very well on the basis of the many social benefits that its product has brought, particularly the more productive, more enjoyable and less fearful use of the natural dark hours. It promotes its product on the basis of these benefits, and on the myth of lighting for crime reduction, to grow or at least maintain its prosperity by the installation of ever more and brighter lights.

The world has changed, however. Sustainable limits to consumption of finite resources and production of waste are being approached or exceeded as the world population continues to grow. While it is not the major consumer of energy or materials, outdoor ambient artificial light including road lighting, 'security lighting', sports lighting, decorative lighting, illuminated signs, escaping internal light from buildings and vehicle lighting, is a substantial minor component and needs to be subject to more rigorous scrutiny of its overall value, taking full account of its many adverse effects (disbenefits) as well as its benefits.

The disbenefits can usefully be related to three categories: outdoor lighting as a whole, light pollution, and avoidable light pollution:

1. **Disbenefits of outdoor lighting as a whole:**
    - Large amounts of coal, gas, oil and nuclear fuels are consumed in generating the electrical energy used to power most outdoor lighting. The processes variously result in air and water pollution, GGEs, radioactive waste and seismic activity.
    - Public lighting is a substantial cost ultimately borne by taxpayers.
    - Exposure to artificial light at night can cause illness as an outcome of endocrine disruption, sleep loss and sleep disturbance.
    - Sleep problems caused by outdoor lighting can also lead to increases in the rate of traffic accidents and industrial accidents.
    - Dark adaptation is reduced by artificial lighting, increasing the risk of road accidents, pedestrian accidents and criminal ambush when moving into adjacent areas that are unlit or less brightly lit.
    - There is statistically reliable evidence that the crime rate increases with the mean flux density of artificial lighting in cities.

2. **Disbenefits from light pollution**
    - Light pollution causes artificial skyglow, which hinders professional and amateur astronomy, handicaps education about Earth's place in the universe and deprives the public of the beauty of night sky.
    - Glare is a form of light pollution. It can be unpleasant and it can degrade visibility, thereby increasing the risk of traffic accidents and surprise assaults.
    - Spill light extends the areas in which criminal acts are facilitated more than deterred by the presence of artificial light at night. On cloudy nights, an increased amount of light pollution is reflected back to the terrain, further facilitating crime.
    - Light pollution includes ecological light pollution, which is artificial light that has any adverse effect on biodiversity. Effects include geographic disorientation of bird migration, restriction of the daily vertical migration of plankton, interference with breeding cycles, incineration of moths etc.

3. **Disbenefits from avoidable light pollution**

The presence of avoidable components of light pollution unnecessarily leads to

- Avoidable waste of natural resources
- Avoidable additional tax burden
- Environmental degradation, including avoidable emission of greenhouse gases
- Avoidable traffic, pedestrian and industrial accidents
- Avoidable facilitation of crime
- Avoidable threats to biodiversity
- Avoidable hindrances to astronomical research, education, recreation and aesthetic pleasure (UNESCO 2007).

Large reductions in outdoor lighting and especially in light pollution now appear to be necessary for environmental, health, safety and social reasons. Particularly because of the compelling need to reduce GGEs, no new lighting should be installed anywhere without independently audited overcompensating lighting energy reductions elsewhere. Furthermore, it is the continuation of existing lighting that has to be justified, not its reduction in coverage and intensity for environmental and social reasons.

Proposals for reduction or removal of existing lighting sometimes generate vehement opposition from people who appear to be afraid of the dark. Another possible reason could be that some individuals ascribe sacred status to light because of the Biblical text 'God is light', the common association of light with goodness and darkness with evil, and the use of candles and lamps in religious and quasi-religious ceremonies. Some theological texts actually state 'Light is God'. The writer has seen a TV documentary in which a church in the USA had a black cloth backdrop to the altar with 'LIGHT' on it in large white letters. It may be difficult to convince people with such views that too much light can be a bad thing, but noncompliance with necessary restrictions will tend to make a bad situation worse for others.

# 5. MANDATORY LIGHTING CONTROLS

## 5.1 EXISTING NATIONAL LIGHT POLLUTION LAWS

Many regions, provinces and states in other countries have mandatory controls on obtrusive light emission and energy consumption of outdoor light sources. Spain has a national law on light pollution but it only applies in the Canary Islands. The honour of being the first country with a *national* law dealing with light pollution across the whole nation goes to Czechia, which included provision for municipal lighting controls in its Protection of the Atmosphere Act of 25 March 2002. When introduction of the Czech law was being debated, opponents with vested interests predicted increases in lawlessness and accidents. Consequently the need for compliance with the light pollution controls was removed from the law despite the absence of valid evidence to justify these concerns. The current version of the Act merely defines light pollution of the air and empowers municipalities to ban skybeams. Many municipalities have done so.

The original form of the Czech law was based on law number 17/2000 of the Lombardy region in Italy. In Lombardy itself, introduction of the regional law had substantial popular support and produced a somewhat surprising result: it revitalised the Italian lighting market by introducing an emphasis on improved technical performance (Bonata 2002). At present (in 2007), 17 of the 21 regions in Italy have laws against light pollution. Of all the regional light pollution laws, regulations and ordinances dealing with light pollution in Italy and elsewhere,

the Lombardy one appears to provide one of the best foundations for other governments to start with (Bonata 2002). However, it was formulated before the exponential growth of outdoor lighting was identified as the key problem, so exponential increases are still possible. Self-regulation does not work as a solution, so in future, laws should also include mandatory reducing caps on total light flux both in regions and nationally.

The world's second national law that included light pollution came into force in the UK in April 2006. Following a House of Commons inquiry into light pollution, the UK Environment Protection Act 1990 was amended by Section 102 of the Clean Neighbourhoods and Environment Act 2005. Artificial light is included in the statutory nuisance provisions. Allowing 'exterior light' to be 'emitted from premises so as to be prejudicial to health or a nuisance' is now a criminal offence. The restriction of the law to light from 'premises' was quite deliberate in order to exclude other important sources of light and light pollution such as streetlights and public transport terminal lighting. The stated intention was to deal with these other sources separately, and action along these lines does appear to be progressing.

In August 2007, the UK Highways Agency issued revised standards for highway lighting. The Personal Injury Accident (PIA) reductions that can be attributed to road lighting for financial justification of new or changed lighting have been reduced substantially, with the effects that fewer road links will now qualify for lighting and the illuminance minima have been reduced (Highways Agency 2007a). Furthermore, in Highways Agency (2007b), the design of the lighting has to comply with the following:

> "2.1 The road lighting shall be designed in accordance with the recommendations of BS 5489-1 Code of Practice for the Design of Road Lighting – Part 1: Lighting of Roads and Public Amenity Areas, together with the additional requirements set out in this Standard.
>
> 2.2 All road lighting shall be designed and installed such that the installation will emit no direct light above the horizontal."

Note that there is no provision for changing the existing spacing of light poles because there is generally no essential reason to do so. Sections of the lighting industry have been claiming for many years that the introduction of fully shielded or full cutoff luminaires would require higher or closer poles or both, but the argument is contrived and specious, relying as it does on maintenance of arbitrary limits in uniformity of illumination. There appears to be no evidence that small reductions in uniformity accompanying the introduction of full cutoff luminaires on existing poles would have any important adverse effects, but there would certainly be beneficial reductions in glare and unwanted light spill.

Thus the UK now has national laws against upwards waste from road lighting luminaires as well as against obtrusive lighting from premises, which would include most advertising signs. This piecemeal approach is better than nothing, but overall control on all forms of outdoor lighting or all sources of outdoor light flux would appear to be a better way to go.

The legislature in Slovenia passed the world's first national stand-alone light pollution law on 30 August 2007. It is largely based on the lighting law in Lombardy, Italy, but includes some usefully stricter limits. In most cases, outdoor lighting must be fully shielded and installed to ensure that no direct emission of light takes place above the horizontal. Residences are protected against light spill. Municipalities are responsible for limiting energy used for lighting, by limiting intensities, numbers of luminaires and hours of use.

In November 2007, the President of Croatia accepted a new law on the protection of nature. Article 31 deals with the definition of light pollution and reasons why limits need to be enforced. It is like the law in Czechia insofar as it would be relatively easy for the lighting lobby to have it rendered ineffective, but this has not yet happened in Croatia. In the meantime, every day that passes is likely to weaken any case for reducing the effect of the law.

## 5.2 FORM OF LIGHTING CONTROLS REQUIRED

Most national and regional governments have been slow off the mark in dealing with light pollution, if indeed they have done anything at all. Whether this is because of ignorance, political disinclination or lobbying by the lighting and power industries is not known.

The introduction of mandatory lighting controls is probably most needed in the developed countries, especially those with high per capita GGEs, but the form of controls could be the same for all countries. Such lighting controls should:

a. allow just enough outdoor ambient artificial light at night in populated areas for wayfinding and safe movement of pedestrians and vehicles,
b. limit unnecessary exposure to artificial light at night to minimise weakening of a key natural defence against breast cancer and other cancers,
c. limit the total amount of outdoor artificial light in the plane of windows of habitable rooms to 0.1 lux, regardless of location, given that even faint light inside bedrooms at night can lead to sleep loss and sleep disturbance, with subsequent increased risk of traffic and industrial accidents,
d. minimise the GGEs associated with all forms of outdoor artificial lighting, including street and public lighting, traffic signal lights, illuminated road traffic signs, illuminated billboards and outdoor display screens, sports lighting and internal artificial light loss from buildings,
e. ensure that the lighting energy sector meets or surpasses national and state obligations under the UN Framework Convention on Climate Change, the Kyoto Protocol and related or follow-on protocols,
f. achieve sustainability in the total national and regional energy usage for the production of ambient outdoor artificial light,
g. eliminate visual amenity loss and traffic hazards arising from glare and distraction caused by inadequately shielded lights and excessively bright illuminated or transilluminated surfaces such as advertising signs,
h. reduce artificial skyglow interference with astronomical research, education and recreation, maintenance of indigenous culture, aesthetic pleasure and tourism,
i. reduce crime to the minimum possible with minimal outdoor light flux while limiting the fear of crime to tolerable levels, and
j. minimise the adverse effects of ecological light pollution (Longcore and Rich 2004) on
    - health and wellbeing of outdoor pets (Wiley and Formby 2000),
    - all forms of biodiversity (Flannery 2005; Rich and Longcore 2005), and
    - primary food production.

One ramification of these findings is the need to act against over-illumination, which has become increasingly prevalent since 1950 (Wikipedia Over-illumination 2008). Another is the need to work towards the reduction and eventual elimination of all outdoor sports lighting

at night. This is particularly important in the case of daylight equivalent levels of lighting used in elite and professional competitions, as spectators as well as the competitors are placed at risk. A further ramification is the need to eliminate most, if not all, architectural and decorative floodlighting, billboard lighting and outdoor video displays. Whatever might be retained, of course, must come at a cost such as correspondingly less light for streets and public places.

Of the possible measures required for enforcement, taxes or other penalties on the amount of light emitted wastefully above the horizontal or its energy equivalent could well have a salutary effect. Where an electricity agency or company provides outdoor lighting services, the customer municipality or individual should not have to pay the energy costs corresponding to any direct light emission above the horizontal or any other avoidable waste.

# 6. AUSTRALIA AS A CASE STUDY

## 6.1 COMPLIANCE WITH THE KYOTO PROTOCOL

This section is about the ramifications of Australia's late reversal, in December 2007, of its policy of the last ten years not to ratify the Kyoto Protocol. Australia is a special case in the context of this report because several key circumstances are quite different from those of most or all other countries. For instance, Australia:

- is heavily dependent on GGE-intensive black and brown coal for electricity generation;
- was allowed to increase its GGEs by 8% over 1990 levels in a generous but short-sighted concession it demanded under the Protocol;
- was allowed further generous concessions in the form of discounted GGEs for stopping land clearing;
- is variously described as the world's worst, or one of the worst, per capita emitters of greenhouse gases;
- does not use nuclear power stations and this seems unlikely to be changed soon, if ever;
- has only a small capacity in renewable energy supplies at present, representing a few percent of total electricity generating capacity;
- has had in place for some years programs to increase energy efficiency and energy efficacy, so that the gains available by further increases might be limited and slow to achieve;
- claims to be on track to meet its 8% GGEs target under the Protocol, although this is disputed by The Climate Group (2008), which claims that the present achieved value is 9%, so further cuts in GGEs need to be achieved by 2010, and
- still ignores the sham of trumpeting compliance with a growth target in the Kyoto Protocol when most other countries had a reduction target.

Regardless of these circumstances, many of the issues that apply to Australia apply elsewhere as well, and Australia can learn from other countries as well as providing useful precedents, as this Chapter indicates by examples.

Having agreed to ratify the Kyoto Protocol, Australia now has a binding obligation to meet its agreed target. Its projected apparent compliance or near compliance has been made possible by generous concessions allowed for reduction of land clearing. Growth in GGEs from fossil-fuel usage has actually increased by much more than the target growth of 8%; for example energy usage in Victoria has actually increased by about 30%. Because any land clearing concession will be smaller in future, compliance with future reductions to values set below 1990 levels will require substantial cuts to existing fossil-fuel usage until renewable energy supply capacity can be increased sufficiently, which is likely to have a lead time counted in decades rather than years. For most of that lead time, Australia and nearly all other developed countries will be participating in a successor climate change response in which the mandatory GGE reductions are expected at present to be in the range of 25% to 40% of 1990 levels by 2020, but could well need to be more severe because some of the natural responses to climate change introduce positive feedback. An example of such responses is the melting of polar ice and the greater absorption of solar radiation by the exposed underlying peat, soil and rock. Australia's supposedly 'smart' action to be allowed an increase in GGEs under the Kyoto Protocol will result in a more onerous compliance burden after 2010 because the base year for all countries appears set to remain as 1990. Regardless, politicians have tended to refer to or imply usage of a base year of 2000 in future GGE reduction agreements. Attention needs to be directed at such politicians to expose their 'spin' as unconscionable.

Although there are many difficulties in implementing a fair global system for GGE reductions, such a system needs to incorporate what may be called the principle of equitability, viz that a burden is minimal for all concerned if it is shared fairly. Compliance with the Kyoto Protocol is known to be a burden and there is no reason why compliance with any follow-on agreement will be different. If any country, state or region does not carry its fair share of the burden, others have to make up the shortfall- climate change mitigation does not allow for 'free lunches'. The same applies to energy use sectors. If the lighting sector is allowed to get away with its massive and irresponsible world-wide expansion in energy usage since 1990, some other energy use sector(s) must face additional reductions.

Debate about what might be considered 'fair' has already begun in international forums. Some developed countries have tended to see this as giving each country a right to emit greenhouse gases in proportion to its gross domestic product, which would tend to maintain the status quo in terms of rich and poor nations. In a nutshell, this approach is unconscionable and appears unlikely to receive majority support. Other countries have argued for allowable emissions to be tied to a universal per capita rate, which will be a small fraction of the present per capita rate of countries such as Australia and the USA. The process required for all countries to reduce their GGEs to a common globally sustainable GGEs rate per capita has already been named 'convergence'. Some of the developing countries would like to see 2050 set as the target for completion of convergence.

Discussion of the rights and wrongs of the present situation is beyond the scope of this document. But what is clear is that compliance with GGE limits is likely to become more onerous over time and increasingly subject to international enforcement. Garnaut (2008) mentions the possibility that the required reduction for Australia by 2050 could be as much as 90%, ie to just 10% of 1990 levels. If this is applied to outdoor lighting in Melbourne, in the absence of additional supplies of renewable energy and increases in energy efficacy the reduction required would be to about 2.8% of the present (2008) level. The governments responsible must not continue to ignore this problem.

## 6.2 DEALING WITH THE IMMEDIATE PROBLEM

There are numerous possibilities in fossil fuel usage reduction for the required GGE reduction in Australia by 2010, but most of them would create significant hardship, for example petrol rationing. Switching unnecessary lights off outright and selectively reducing the wattage or disabling a proportion of other lights are among the easiest to do. Reduced street lighting after a curfew, say 10-30 pm or 11 pm as in AS 4282-1997 or 1 am, 2 am or 3 am as is applied already in many places or under active consideration (eg Connecticut DPUC 2008, p 133) is a possible variant or additional measure. Sufficient experience already exists to be sure that reducing lighting in a sensible fashion not only reduces GGEs but actually saves money. This is in contrast to most other GGE reduction methods, which actually cost money.

Another possibility is to use lamps with increased energy efficacy, following a recommendation by the UN International Energy Agency (IEA) (http://www.iea.org). Accordingly, the governments of Australia, Brazil, Canada, Eire, USA and Venezuela have already decided to phase out incandescent (tungsten filament) lamps that can be replaced by compact fluorescent lamps (CFLs). CFLs can produce as much light while using only about a fifth as much energy. Generally there are to be no bans on usage of incandescents, just bans on sales (Wikipedia Light Bulb 2008).

Unfortunately, several problems will limit the effectiveness of replacement of incandescent lamps by CFLs and other high intensity discharge (HID) lamps:

- Anecdotal accounts on the Internet suggest that the actual GGEs reduction could fall short of that expected because of a tendency for people to use nearly as much energy after converting to CFLs by increasing the number of lamps in use to get more light.
- HID lamps generally contain mercury (some more than others) but few governments have done the right thing and ensured that all used HID lamps are collected for mercury recovery or proper containment of the mercury in toxic dumps. Mercury can stay toxic even longer than radioactive waste.
- Most CFLs at present are not usable with dimmers, so existing dimmer switches have to be removed or the dimmers have to be bypassed electrically.
- For a given amount of electricity used by tungsten lamps, HID lamps other than sodium types produce much more of the blue light that is now accepted by the World Health Organisation as likely to be a risk factor for breast cancer.
- The long lifetime of CFLs is much reduced if the lamps are switched on and off frequently, as tends to be the case with domestic indoor and outdoor lighting.
- Tungsten lamps that only come on when activated occasionally by movement sensors do not use as much energy as CFLs that have to be left on all night because they don't work with the sensors or other electronic switches.

## 6.3 VICTORIA AS A SPECIFIC EXAMPLE

### 6.3.1 The extent of the problem

Victoria uses brown coal for most of its electricity generation. Lighting typically uses about 10% of the electricity supply, so reducing lighting by one tenth, for example, would reduce electricity usage and associated greenhouse gas emissions by 1%. It would appear much easier and quicker to reduce overall electrical energy usage by such an amount than to

introduce an equivalent increase in the renewable component of the electricity supply. In practice, it may be possible to reduce lighting by several times 10% without greatly impacting on overall amenity.

Outdoor lighting in Victoria is a prime candidate for corrective action because it is grossly in breach of the Kyoto Protocol at present, and it would be unfair to expect other energy use sectors to suffer extra cuts to make up for irresponsible excessive growth in lighting over the past 17 years and earlier. Although electrical energy use in Melbourne is a large part of the total for all Victoria and fixing lighting in Melbourne would have a useful impact in reducing the state's overall electrical energy use, it is neither necessary nor desirable to restrict the proposed lighting reform to Melbourne. As mentioned above, Figure 1 is more-or-less indicative of the situation throughout Australia. Regardless, the abundance and consequent large-scale use of brown coal in Victoria makes the Victorian problem relatively worse, because growth has to be reversed to shrinkage and the land clearing concession that allowed large increases in fossil fuel usage under the Kyoto Protocol will be much less applicable as an offset in future. Victoria's use of brown coal will tend to increase the compliance burden on the other Australian states unless that usage is cut by a factor substantially larger than the target reduction.

With this background, proposed lighting reductions are calculated below. They are assumed to be applied over all sources of waste outdoor lighting flux, which can be expected in cities to be roughly equal contributions from road/path lighting, illuminated signs and internal light loss from buildings. This does not necessarily mean equal contributions from the energy inputs to these categories. If one of these sources cannot be reduced for any reason, cuts required in one or both of the other two would need to be correspondingly larger.

From the data used to generate Figure 1, in the absence of intervention to reduce lighting growth the increase in artificial skyglow over Melbourne by 2010 will be 38 times the allowed 8% increase applying to 1990 GGEs under the Kyoto Protocol. Skyglow is several processes away from GGEs but its changes are a reasonably good proxy for changes in total outdoor light flux which in turn is a reasonably good proxy for changes in energy use by the outdoor lighting sector. That energy use is closely coupled to changes in the associated GGEs. Ignoring whatever likely small disproportions occur over time between increases in skyglow and GGE increases from energy use for outdoor lighting, the outdoor lighting sector would need its 2010 GGEs to be reduced by 72.5% of its expected 2010 value in order for it to comply with the Protocol. Thus all but about 27.5% of all present outdoor lighting in Melbourne, nearly three quarters of it, would need to be decommissioned, or equivalent energy use reductions made in some other way, eg by use of lighting curfews and increased efficacy of conversion of electricity into light.

Another way of looking at the problem is to consider that the total of new and increased lighting since 1990 or its equivalent capacity needs to be reduced to just 2.7% of that total for sector compliance with the Protocol. Even if the proxies and observations are in error by an unlikely total factor of 30%, say, and in the right direction, the required cut in new and increased lighting since 1990 would still be to less than 4%, still massive. It would appear that the state and federal governments have been 'asleep at the wheel', so to speak, while new lighting and upgrades have been installed in a fashion that has clearly been way out of control at state and federal levels.

In a nutshell, growth in outdoor lighting in Melbourne has been excessive and is far from compliant with the Kyoto Protocol at present. The situation is probably similar over the whole of the populated areas of Australia. This is a priority matter for the federal and state governments to deal with. By itself, an early fix might not achieve overall compliance for Australia but would be a useful step in the direction required.

Clark (2003) drew attention to reliable positive correlations of crime and outdoor lighting in the Melbourne CBD and on national scales. Melbourne city officials and the police were advised accordingly then and have been reminded since. Despite this, street and pedestrian lighting has been increased several times as a supposed deterrent in the trouble spots. Crime has actually continued to increase, eg assaults have increased by 24% to 2064 since 2003-2004, along with comparable increases in sexual assaults, robberies and homicides (The Age 2008). A similar blunder has been made in increasing the illumination of metropolitan railway stations to daylight levels. The transport officials involved have failed to provide crime figures supposed to justify the action. All they have managed to provide instead is a claim that customer satisfaction has improved. Presumably this reflects a decrease in the fear of crime, but it comes at a cost that is being covered up.

It is important to understand the processes in circumstances like these examples. Firstly, a public facility such as an 'entertainment' precinct (bars, discos, singles clubs) or public transport station receives media publicity about street crime. There are public calls for counter action such as more police and, through almost universal confusion between feeling safe and being safe, more outdoor lighting. Politicians tend to choose more lighting as it is a much more visible sign of their action for a given expenditure. Increased lighting increases patronage because people feel safer. The number of crimes would increase in step with patronage if the crime rate remained constant, but the rate typically increases by a few percent for each tenfold increase in total light flux (Clark 2003). So the total crime figures rise disproportionally, and the media naturally find this newsworthy. More light is added as a supposed fix and the effect compounds. Calls by the writer and others to reverse the process are resisted by the owners and operators of the facilities as a threat to their profitability. In the writer's case, the police have justified their support for ever more lighting by claiming that even if lighting does increase the crime rate by a relatively small amount, their task is to reduce the fear of crime as well as to fight crime. Perhaps the police regard any proposed reduction of lighting as a threat both to their own feelings of security and to their job security. They need to think again, with emphasis on their actual safety and reducing the need for stress-related leave.

Ultimately, the way to reduce fear of crime is to reduce the actual crime rate. Minimising outdoor lighting can do this while saving money and reducing the many other adverse effects of non-essential lighting.

### 6.3.2 Trials and fixes

Across Australia, the cost of public lighting and lighting of streets other than main roads is typically the largest single item of expenditure for local governments. Paying for main road lighting is usually the responsibility of a government roads department. Concerned by growth in the electricity bill for public lighting, a group of local councils in Melbourne has been carrying out trials to determine if the use of T5 linear fluorescent lamps could help cut the lighting bill and GGEs without reducing the amount of light provided for suburban streets.

At present most of the suburban streets are lit by 80 watt mercury vapour (80 W MV) lamps. Many of the luminaires in use are of the 'flower pot' type, which should be regarded as obsolete because they emit an excessive proportion of upward waste light. Regardless, new luminaires of this type are still being installed in some council areas. Otherwise, most of the newer 'cobra head' street lights have about 10% upward waste, still quite a lot to pay for and send into outer space.

The trial luminaire seen by the writer has twin 14 W linear fluorescent lamps giving about the same amount of light on the ground as that from the usual 80 W MV types. The amount of upward waste with the tubes set horizontal appears to be similar. However, the trial installations have the luminaire canted at about 20 degrees to the horizontal, and the upward waste and maximum spill are thereby substantially greater. Discussions with trial personnel and a designer indicated little interest in doing anything to limit this unwanted spill and upward waste.

The applicable Australian Standard (AS/NZS 1158.3.1:2005, *Lighting for roads and public spaces*) has a provision for property owners to have excessive light spill from street lights reduced on request. Accordingly the writer requested that the 80 W MV cobra head semi cutoff luminaire in the streetlight outside his home be changed to a full cutoff type with a 50 W high pressure sodium lamp (HPS). Alternatively, the writer requested that the common procedure for dealing with the problem be applied, viz that the existing luminaire be fitted with a shield or that a lens sector be painted to reduce excessive light spill into the property.

The reason for proposing the HPS lamp is to reduce the power consumption by 38% (or even more with a commercial electronic ballast) while putting more illumination on the road. The idea was to show how very substantial reductions in electricity usage for street lights could be achieved with established technology. Bear in mind that almost all of Melbourne's main roads are already lit by HPS lamps because they are more economical to operate than MV. The council officer's letter in reply stated that based on advice from the council's power and lighting contractor,

> "we have determined that, at this stage, there is no need to change the existing luminaries [sic]. We acknowledge that you disagree with some or all of our arguments, yet, at this stage, our determination stands. If, in the future, affordable and appropriate technologies become available then Council will consider luminare [sic] changeover."

This is not just nonsense from officialdom about a single obtrusive streetlight and the supposed inappropriateness and non-availability of better technology that is in widespread usage throughout Melbourne and elsewhere, let alone the alternatives of paint or sheet metal and rivets. Many other council streetlights in Melbourne are similarly obtrusive and wasteful, but residents are not made aware of their right to have the problem fixed. Nor are they aware that sizeable portions of their council rates are wasted on MV lighting that is deprecated elsewhere because of its poor efficacy and the toxicity associated with the relatively large quantity of mercury in used lamps and released to the environment from broken lamps. For example,

> "The use of MV lamps should be discouraged... in outdoor applications they should be replaced with one of the other gas discharge lamps. The disposal of mercury vapour

> lamps require [sic] special methods because of the mercury inside the lamp" (NRCan 2006).

This example illustrates why power and lighting companies should not be asked to advise on matters that will affect the amount of electricity they supply. It also shows that higher levels of government need to show leadership in imposing rational uniform controls on outdoor lighting. This includes the need to override Australian Standards where these are in conflict with environmental requirements.

This example prompts a comparison between MV and HPS lamps used in the existing street and road lighting of Melbourne and the trial fluoros mentioned above. Firstly, here is a verbatim extract from a document of the Australian Greenhouse Office (AGO Guide 2007):

> "5. Environmental Issues
> Lamp disposal is problematic due to the content of toxic heavy metals, in particular mercury. High pressure sodium lamps pose less environmental risk. For example a 50W HPS lamp contains only 0.1 mg of mercury compared to 80w mercury vapour lamps which contain about 14 mg.
> Modern fluorescent lamps have about 1mg of mercury compared to 30mg in older lamps. There are some companies which specialize in the recycling of lamps and recovery of heavy metals. Recycling is more preferable than landfill disposal."

Secondly, the following information comes from a table headed Energy Efficient Street Lighting and a graph headed 'Theoretical Lamp Life' in the same AGO publication. The data came from lamp manufacturers and suppliers. Other sources give somewhat different relativities and a more realistic indication of the reduction in MV output over time.

**TABLE 2. Properties of lamps for street lighting**

| | HPS 50 W standard | MV 80 W | T5 Fluoro 2 x 14 W |
|---|---|---|---|
| **Years to 50% failure** | **6.2** | **4.2** | **2.5** |
| **Lumens at 100 hours** | **3600** | **3800** | **2700** |
| **Derated lumens** | **2700** | **3800** | **2700** |

On the basis of this information, one wonders why so much effort has gone into the T5 fluoro trials mentioned above. Taking into account the hazard of blue light exposure at night and the much greater emission of blue light from MV and T5 fluoros relative to HPS, HPS appears to be a far better choice. In other words, it has a lower technical risk in this respect than whiter or bluer light sources have. Furthermore, because of its low output of blue light, HPS light is less scattered by air molecules, meaning less skyglow. HPS has tended to fall out of favour recently because of claims of superior face recognition given by whiter light sources, and therefore reduced fear of crime. But this ignores the evidence that increasing visibility with lighting is of more assistance than deterrence to criminal acts.

There is a related tend to replace HPS by metal halide lamps, which have a whiter output and better colour rendition. But there are disadvantages such as greater cost of the lamps, shorter life, lower energy efficacy and increased scattering by air molecules (eg Harder 2007), and reduced visibility of road signs that use red, orange and yellow (Keith 2004).

Considering that *low pressure* sodium lamps are more efficacious than HPS it would seem worthwhile to pursue ways of using these lamps instead of HPS in order to achieve further reductions in GGEs (eg Lamptech 2003). Luminaires with better upward waste light control than hitherto used would need to be developed. In the meantime, HPS would appear to be the best all-round choice. This is especially so as HPS lamps are available with power consumptions of as little as 35 W, which would be valuable in lighting energy usage reduction projects while maintaining the use of existing poles and providing sufficient lighting for mobility safety.

# 7. CONCLUSIONS

In Melbourne, the observed/extrapolated growth in artificial skyglow from 1990 to 2010 is likely to be *38 times* the maximum growth that could have been expected if lighting energy usage complied with the Kyoto Protocol maximum growth of 8% in greenhouse gas emissions generously allowed for Australia. Indications are that lighting growth elsewhere in Australia has been comparably excessive. Compliance of the lighting energy use sector with the Protocol by 2010 would require as much as 97% of the increase in installed lighting since 1990, or its equivalent in power consumption, to be removed.

While anthropogenic greenhouse gas emissions continue at unacceptably high levels in Australia, no foreseeable improvements in energy efficacy or renewable energy supplies will allow more than minor mitigation of the reduction burden in the short to medium term. All outdoor lighting must share fully in meeting this burden or some other energy use sector will have to bear additional cuts.

Quite small amounts of stray artificial light entering bedrooms at night can interfere with sleep. This tends to result in increases industrial and traffic accidents next day. Light exposure at night can interfere with the body's melatonin cycle. The adverse consequences of this are still emerging. The World Health Organisation has accepted that shift work increases the risk of cancer in humans, probably through interference with the melatonin cycle. Present lighting standards generally take little or no account of these adverse effects.

The suppression of melatonin is strongest with blue light. Sodium lamps with orange light output are commonly used for road lighting. Lighting companies are pressing for their replacement by more expensive types of lamp that use more electricity and emit greater amounts of blue light.

Environmental, ecological and health reasons justify substantial reductions in outdoor ambient artificial light flux at night. Reductions will tend to increase fear of crime but reliable scientific evidence indicates that lighting reductions will also reduce actual crime, an outcome that should take precedence. Lighting reductions may increase traffic accidents in some circumstances, but this effect is now known to be much smaller than was believed for many years.

Excessive outdoor light levels appear to be a consequence of individual and corporate ignorance, carelessness, selfishness and greed. Self-regulation of lighting use by industry has failed in aspects such as illumination of outdoor advertising signs. Excessive lighting

contributes to artificial skyglow, which is becoming an ever more serious hindrance to astronomical research and education, and to maintenance of indigenous culture. Much of the problem arises from stray light emitted from light fittings in directions just above the horizontal. Redirecting this light towards the ground may allow useful reductions in lamp wattage, but lighting and power companies tend to oppose this. Increasing skyglow is primarily a consequence of continuing increases in the number and power consumption of outdoor light sources.

The observed exponential growth of skyglow indicates unsustainability, which must be curbed. Mandatory caps on regional total light flux can certainly be justified, but there is an even stronger case for mandatory caps on energy used for lighting. Annually reducing energy caps must be introduced as a matter of urgency if the energy used for outdoor lighting is to be reduced towards compliance with the Kyoto Protocol. Such compliance could usefully assist in achieving national compliance with the Protocol across all energy use sectors.

Follow-on control of greenhouse gas emissions after the Kyoto Protocol period ends in 2012 is likely to be onerous. For Australia, the 2050 target could be set as small as 10% of the 1990 value. It appears unlikely that either the Protocol target of 2010 or its 2020 and 2050 successors could be achieved solely by any foreseeable availability of renewable energy, so that substantial ongoing reductions in fossil-fueled energy use would appear to be necessary. Outdoor lighting should be targeted particularly because of its profligate expansion since 1990. The level of outdoor lighting in Melbourne might need to be reduced to only 2.8% of the present (2008) level, and comparably severe cuts are expected to be applicable to other Australian cities and towns. Commercial decorative lighting and illumination of advertising signs are considered to have the highest priorities for reductions in the outdoor lighting energy use sector. Sports lighting also needs to be reduced or eliminated. Rapid phasing out of most if not all of these uses of illumination appears to be justified. Few if any concessions will be possible. Proposals to power illumination in these categories by renewable energy supplies should be regarded as unacceptable ploys because environmental and health aspects of excessive artificial light at night are ignored. If any solar-generated electricity is available it should be used to boost the non-fossil-fueled component of the grid supply instead.

There are unresolved scientific issues about the road accident hazards of advertising signs that are visible to drivers, especially for signs that are artificially illuminated, or self luminous as in video-capable screens. If the government is serious about road safety it needs to eliminate such signs in the meantime because of the strength of the prima facie case that the signs are devised and intended to attract attention and are therefore a potential distraction for drivers. No illuminated advertising signs other than company names on premises open for business should be permitted in positions where they can be seen by drivers, and even for permitted signs there is a need to shield light emissions from travelling at or above the horizontal.

# 8. RECOMMENDATIONS

Based on the information presented in this paper, all levels of government in Australia and in most other countries should implement the following:

a. Apply mandatory outdoor lighting strategies and controls, including provisions to:

- limit *total* external incident artificial illuminance in the plane of windows of habitable rooms to 0.1 lux regardless of location of the dwelling, disregarding the lighting zones concept of the International Commission on Illumination (CIE) as perpetuating lighting practices that are inimical to health, safety and energy conservation,
- conserve energy and assist seeing by reducing glare, limiting spill light and preventing overbright lighting,
- require full cutoff shielding of outdoor luminaires in all cases, including commercial lighting, road lighting and sports lighting, with exemptions only by specific exception subject to public scrutiny and appeal,
- limit the size, luminance, intensity and hours of operation of all existing illuminated advertising signs and outdoor video displays, and cap their total energy use (which may well need to be subject to annual reduction until the energy use has reached small or zero values),
- ban all new illuminated advertising signs other than on-premises exceptions,
- ban all outdoor use of laser beam displays,
- ban all advertising searchlights and laser skybeams,
- ban all upwardly aimed floodlighting,
- specify curfew times for certain types and locations of outdoor lighting,
- limit the emission of internal light at night from doors, windows and skylights,
- avoid waste of resources by inappropriate use of lighting to try to control crime and graffiti, and
- apply reducing caps to outdoor lighting energy usage in line with international obligations to reduce GGEs, and insist that only a 1990 base year should be used in lighting energy constraints under the Cities for Climate Protection (CCP) scheme.

b. Educate the public about actual lighting effects on crime and the fear of crime.

c. Discourage the use of mercury vapour lamps.

d. Institute a mercury collection service for all discarded lamps containing mercury.

e. Encourage the continued use or revival of *low pressure* sodium lamps for high energy efficacy where appropriate, and investigate their value for essential lighting in areas where graffiti deterrence is also required.

f. Introduce national and regional lighting strategies with laws and regulations, including mandatory technical constraints in cases where the relevant national standards do not adequately represent the national interest in general or the specific interests of environmentalists, ecologists, and professional and amateur astronomers.

In applying these recommendations in countries other than Australia, appropriate allowance may need to be made for differences in political, legal, economic and cultural systems.

# 9. ACKNOWLEDGEMENTS

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