Attachment 4 - Barrow Island Light Survey 9-11 March 2004. Report to ChevronTexaco Australia Pty Ltd by Pendoley Environmental, March 2004.

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PROPOSED GORGON GAS DEVELOPMENT
BARROW ISLAND LIGHT SURVEY

9-11 MARCH 2004

REPORT TO SINCLAIR KNIGHT MERZ
BY
PENDOLEY ENVIRONMENTAL PTY LTD

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1 Introduction

This study was commissioned by Sinclair Knight Merz on behalf of ChevronTexaco Australia. It forms a component of the environmental engineering and biological risk assessment for the Gorgon Gas Development project.

1.1 Literature Review and Background

Large oil and gas processing facilities are typically operated 24 hours a day. Illumination is therefore required for night shift operators working in and around facilities. Historically the most common type of light used in industrial settings are unshielded high pressure sodium vapour, low pressure sodium vapour, halogen and fluorescent lights which are generally elevated high above the facilities.

All of these anthropogenic light sources emit in the visible range of the electromagnetic spectrum. Visible light falls between short wavelength ultra-violet (<400 nm) and long wavelength infra-red (>700 nm) radiation. The spectrum of visible light is shown below and ranges from 400 nm (violet) to 700 nm (red).

<400	400-450	450-500	500-570	570-590	590-610	610-700	>700
ultra-violet	violet	blue	green	yellow	orange	red	infra-red

White light, such as that produced by most electric light sources, consists of a mixture of the different colours of light.

The amount of photopic (light adapted) light falling on a unit of area over a given distance is termed illuminance and is measured in lumens/m^2 or Lux. Lux is a measure of the power of visible light and depends on the sensitivity of the human eye. It is based on the CIE Luminous Efficacy Curve for photopic conditions (Figure 1). The CIE curve has minimal response to light at the ends of the spectrum (400-500 nm and 625-700 nm) and has a peak response at 555 nm. Hence the quantification of light emissions in Lux will include little of the light that is emitted between 400-500 nm and 625-700 nm and will be an underestimate of the amount of the total light that is being emitted.

Some typical illuminance values are:

Bright sunlight	100,000 lx
Cloudy day	10,000 lx
Night sports field	200 – 1,000 lx
Residential street	1 – 10 lx
Full moon	1 lx
Cloudy moon	0.25 lx

(Sources www.schorsch.com and www.pc.ibm.com)

The amount of illumination received by a sensor (or eye) varies inversely with the square of the distance from the point source. So if the distance from a point source is doubled the intensity is reduced by a factor of 4. Tripling the distance decreases the intensity by a factor of 9 and so on. As the distance from a point source increases the intensity of the light that can be detected decreases.

The two main sources of light are incandescent and gas discharges. Incandescent sources can be anything that produces light when heated to 1000°K or more. Natural incandescent sources are candle light fire and the sun. Man made sources are tungsten filament light bulbs. Passing an electric charge through a gas can also produce light. The colour of the light is a function of the gas used. The intensity of the light is a function of the density of the gas. High pressure light sources will produce a more intense light relative to a low pressure sources (i.e. high pressure sodium vapour vs. low pressure sodium vapour). Common gas discharge sources are sodium vapour, mercury vapour and fluorescent lights.

Light sources are characterized by their colour, temperature and spectral power distribution. A light source with a cool colour temperature, such as a candle flame (1900°K) will emit greater amounts of long wavelength red/yellow light than short wavelength blue/green light. Conversely the much higher temperature of the sun (25,000°K) emits light weighted towards the blue end of the spectrum. As the temperature of the source increases, the colour of emitted light moves from red to yellow to blue.

Lights are generally described using a spectral power distribution curve. This is a visual profile of the colour characteristics of a specific light source. A light type emits different amounts of energy at each wavelength across the visual spectrum (380nm-780nm). The graph of the power emitted across the spectrum is termed the Relative Power Distribution Curve for that light source.

The power distribution curves show consistent characteristics for the two main light sources. Incandescent light sources such as the sun or a flame emit an even power output across the spectrum. Gas discharge sources on the other hand are characterized by spikes and a marked unevenness in the amount of energy emitted at different wavelengths.

Turtles and Light

The many properties of light, temperature, intensity, wavelength, directivity and polarization are all thought to play a role in sea turtles hatchling orientation (Lohmann, Witherington et al. 1997). Brightness of a light is a function of intensity and wavelength and how the eye perceives light.

Electroretinography (ERG) studies (Granda and Dvorak 1977) have shown that Green turtles are most sensitive to violet to yellow light (400nm- 600nm). Relative to the human eye this is skewed toward the blue end of the spectrum (Lutz and Musick) and is thought to be an adaptation to reduce the attractiveness of the rich yellow – red light of the rising and setting sun and moon. It is this light that is not registered by standard photometers measuring in Lux.

Physiological studies by Granda and Dvorak, 1977) have shown that sea turtles see both colour and form well. These researchers have shown that the spectral sensitivity curves for sea turtles fall between 400 and 700nm, with peak sensitivity in the short wavelength region between 400 and 640nm. Sensitivity falls off rapidly between 640nm and 700nm. Light emitting in the short wavelength blue, green and yellow range is therefore thought to be most disruptive to sea turtle orientation.

Industry sponsored studies have been carried out on electric lights and gas flares at Thevenard Island (Hick 1995) and Varanus Island (Hick and Caccetta 1997; Pendoley

2004a in prep). Similar methods and equipment were used for this current study on Barrow Island.

1.2 Objectives and scope

The primary aim of this project was to measure the intensity and spectral signature of electric lights and flares typically found on Barrow Island.

The existing light field on east coast Barrow Island beaches was also measured to provide a baseline measure of the existing light field at two east coast turtle nesting beaches prior to development activities.

2 Methods

The field survey took place over 2 nights, March 9-11, 2004. The survey team comprised K. Pendoley and A. Vitenbergs both of Pendoley Environmental Pty Ltd.

The field light monitoring program was conducted using an Ocean Optics USB2000 miniature spectroradiometer. The measurable light levels and spectral characteristics were gathered from point source lights at the WAPET Camp (measured from Yacht Club Beach), the Landing (Plate 6), the Terminal Tanks area (Plate 7) , the suck back pump on Terminal Beach (Plates 8 and 9), the Central Processing Facility (CPF) and the Base area. Measurements of the CPF and J Station flares were also made. Measurements were made up to 500 m from light sources. This was the limit of the spectroradiometer's sensitivity to the individual light sources. Baseline light measurements were made on fixed bearings from the beach sites (approximately 90°, 180°, 270° and 360°).
GPS positions were taken to allow sites to be revisited over time. Originally this survey was timed to coincide with a late evening moonrise (>50% moon phase, waxing moon), however that survey was delayed due to tropical cyclone Evan. The moonrise during the rescheduled survey (March 9-11) was earlier in the evening (2025 hrs March 9 and 2110 hrs March 10) and did not allow time for measurements both before and after moonrise at all locations. The moon was waning at the time of the survey; phases were 93.5% March 9 and 86.8% March 10. It is important for any questions about why measurements were not made both before and after moon rise and also for anyone who might do future monitoring,

The passage of tropical cyclone Evan caused some damage to field lighting. Consequently the first night of the survey the Terminal Tank lights were not operational. Access to electrical maintenance personnel was limited since the staff were involved with repairs throughout the field. Consequently, the detail on field lighting contained here is a reflection of the limited amount of time that electrical maintenance personnel could spend assisting this project.

3 Results

Table 1 is a list of the spectral measurements collected over the two nights of March 9 and 10, 2004. The light files are coded for location as follows.

YC	Yacht Club
TB	Terminal Beach
TL	The Landing
CPF	Central Processing Facility
FB	Flacourt Bay
JF	J station flare
B	Base area

Selected spectra have been graphed and the figure numbers are also listed in Table 1 for reference. Each survey location is shown in the applicable Plates (1-5). Relative power distribution curves (spectra) are shown in Figures 1-5. The results are presented by location below.

Yacht Club Beach – Figure 1, Plate 1

Lights were measured from two locations on Yacht Club Beach, YC1 and YC 2. The target lights (both measured from YC1) were the twin 80 W sodium vapour lights behind the gym in the parking lot (Fig 1a) and the 400 W sodium vapour light on the mess (Figure 1b). Only the gym light was detectable from YC2, at a distance of 285 m. All other scans (north, south, west and east) from these two locations produced spectra with light signals undetectable above base line noise and is representative of a dark night sky. (e.g. Fig 1d).

The sodium vapour light spectra show the characteristic spiking of gas discharge sources. The peak at 500nm is in the blue region; however most of the light is concentrated in the yellow/orange/red region between 570 and 650 nm.

Terminal Beach – Figure 2, Plate 2

Spectra’s were collected from four locations on Terminal Beach; at the suck back pump, 100 m along the beach, 192 m along the beach at the creek bed and 500 m along the beach from the rocks at the south end of the beach. North, south, east and west spectra were collected from each location (Fig 2a-2d) as well as scans specifically targeting the 80 W sodium vapour light at the suck back pump from each location (Fig 2e – 2g). Fig 2e also shows the increase in light intensity that occurred as the sodium vapour suck back pump light warmed up after turning it on. All but the scans specifically targeting the suck back pump light produced spectra characterised by baseline noise (no light signals detectable). The 80 W sodium vapour light at the suck back pump was detectable from a maximum of 192 m.

A scan of the sky above the terminal tanks is shown in Fig 2h. Little sky glow was observed over the tanks from the beach and the spectral scan of the sky over tanks from the suck back pump (583 m away) found no signal detectable above background spectrometer noise. A representative 400 W sodium vapour light was measured from 25 m away and is shown in Fig 2i.

An example of moon light is shown in Fig 2j and was measured from the suck back pump location with the light turned off. The spectra shows the characteristic even power distribution across the spectrum, which is typical of an incandescent light source, peaking at 550 nm.

The Landing – Figure 3, Plate 3

400 W sodium vapour lights were present at the Landing. Scans of these lights from 30 m and 80 m are shown in Fig 3a. Because these lights are held within a box structure it was possible to scan them as shielded lights by collecting spectral response of the sky glow over the light from behind the fixture. The result is shown in Fig 3b and is indistinguishable from baseline noise.

Central Processing Facility – Figure 4, Plate 4

The incandescent emissions from the CPF flare are shown in Fig 4a (from 946 m), Fig 4b (from 723 m) and Fig 4c (from 126 m). These spectral emissions are faintly detectable for 723 m and clearly show the spectral emission continuum across the wavelengths, peaking at 700 nm, from 126 m. This flare has a flow rate of ~8,500 m^3/day.

The same range of distances was used to measure the bright white lights at the CPF. These lights were labelled as high pressure sodium (HPS) and low pressure sodium

(LPS) on the as built drawings for the facility however the spectral scan indicates these lights are actually metal halides (Fig 4d-4f). A visual assessment of the lights further showed they did not emit the characteristic yellow coloured light generally seen in sodium vapour lights (see front page plate). Figure 4f clearly shows the strong spectral emissions spiking between 400 and 600 nm.

J station flare – Figure 5, Plate 5

The J station flare was measured from 2 distances, 168 m and 371 m (Fig 5a). The spectra are characteristic of incandescent light sources, emitting strongly from 600 nm onwards (orange/red region) with a peak in emissions occurring at 700 nm.

The greater flow rate of the J Station flare (~ 7 times) over the CPF flare is reflected in the relative intensity signals with the J station signal 7 times greater than the CPF flare.

Base – Figure 6, Plate 5

Two other light types typically found in industrial settings were scanned at the Base area, a mercury vapour light (Figure 6a) and a 36 W Fluorescent (Figure 6b). Both are gas discharge lights and are characterised by the spiked and uneven power spectrum that is typical of these light sources.

The mercury vapour is common in workshop settings and produces a bright white light that may be tinged with green as a result of strong emission spikes at 400 - 500 nm. Similarly the fluorescent light is a bright white light that emits strongly from 400 – 650 nm with spiking between 400 and 550 nm.

4 Discussion and Conclusions

- The light types commonly used on Barrow Island include; Sodium vapour, 80 W, yellow street light style, common at separator stations and in parking areas
- Sodium vapour 400 W, yellow box style, common in field locations such as the Landing, the Terminal Tanks, separator stations, airport, parking and lay down areas.
- Fluorescent 18 W (2’ long) and 36 W (4’ long), white light, over doorways to buildings, and control rooms at separator stations
- Metal halides, bright white at the CPF facility.
- Mercury vapour, bright white lights with or without a green tinge, in workshop areas
- Incandescent tungsten bulbs, bulkhead lighting around camp (not measured but identified by the field maintenance staff).

This list is not exhaustive; there was not sufficient time to fully document all of the light locations, types and wattages on the island. It is likely a more thorough survey would identify additional light sources and types such as halogens and incandescent and possibly additional metal halide lights. This study focussed on the lights most commonly used and those most visible from turtle nesting beaches.

The most common light type used in outdoor field locations at Barrow Island are the sodium vapour lights (nominally 80 W and 400 W). With the exception of the suck back pump light, these lights are typically located atop 6-8 m tall poles and are oriented at ~20° from vertical. These are the lights that are most visible to turtle nesting beaches near the Landing (Plate 6), the Terminal Tanks (Plate 7), Terminal Beach suck back pump (Plates 8 and 9) and the WAPET Camp locations (Plate 10).

Less common are the metal halide (CPF), fluorescent and mercury vapour lights.

While these lights are visible over long distances as point sources their spectral emissions were not detectable as electrical signals over more than several hundred meters. The quantification of light emissions is a function of numerous factors including light source type and power (wattage), detector sensitivity, ability to target a light source, distance to the light source and atmospheric scattering. Because the measurement of light is limited by the sensitivity of the measuring instrument and it is not unusual for a light (and particularly a glow) to be visible to the human (and sea turtle) eye but undetectable by an instrument (ie spectrometer, lux meter, illuminance meter). It cannot be assumed that because an instrument cannot detect a light emission that the sea turtles cannot see it.

Studies on the response of sea turtle hatchlings to different light wavelengths suggest that while they are able to see light up to 640 nm, hatchlings respond most strongly to short wavelengths, particularly at low light levels at night (Witherington and Bjorndal 1991; Witherington 1992; Pendoley 2000; Pendoley 2004a in prep). Sea turtle hatchlings integrate the light field across a 180° horizontal field of view when engaged in sea finding. Because of this they are often susceptible to misorientation from low intensity light glow spread across a wide horizontal area. Distant point sources of light are thought to be disregarded as cues by hatchlings since they resemble stars. However bright point sources of light will attract hatchlings if they are located close (distance depends on the type and intensity of the light) to the animal. The hatchlings become trapped by the light and blinded to the surrounding darkness.

Consequently the lights most disruptive to sea turtle hatchlings on Barrow are likely to be the bright white lights that emit low wavelength light, such as fluorescent, metal halide and mercury vapour. These low wavelength blue/green emissions of these lights are strongly detected by dark adapted eyes (scotopic vision) and are therefore likely to be highly disruptive to sea turtle hatchlings at low intensities at night. These lights were not found at any of the coastal locations monitored during this survey.

The lights least disruptive to sea turtles are the flares and the sodium vapour lights that are currently used at the coastal locations on Barrow. These lights emit at higher wavelengths to moonlight and are therefore less attractive to hatchlings in comparison. The yellow light also causes less atmospheric scatter than white lights, reducing glow in the sky (www.darksky.org/handbook/le-hb-v1-14.html), with LPS lights producing less glow and scatter than HPS.

Under certain conditions however these lights can still be disruptive to Flatback hatchlings. Whilst conducting the light survey, a group of ~30 Flatback hatchlings that had been rescued from a perentie during the day were released that night on Terminal

Beach. Half of the group was released within 100 m of the light and the other at 192 m from the light (at the creek bed location), all of the animals oriented along the beach towards the suck back pump light and were found half an hour later trapped within the light spill at the base of the light.

Additional biological surveys are planned for April 2004 to further study the impacts of different light types, intensities and presentation (bare bulb vs. shielded) on Flatback hatchlings.

In summary

- HPS and LPS are the most common light sources on Barrow Island
- The existing sodium vapour lights are visible from turtle nesting beaches however little of this spectral energy reaches the beaches.
- The sodium vapour lights produced little visible sky glow from east coast nesting beaches.
- Individual lights can be detected up to a maximum of 250m (depending on type and wattages) using the Ocean Optics USB2000 spectroradiometer.
- Most scans of the night sky at beach locations registered little or no light above the baseline noise signal.

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Plate 6: 400W sodium vapour lights at the Landing

Plate 7: 400W sodium vapour light at the Terminal Tanks

Plate 8: 40W sodium vapour light at the suck back pump

Plate 9: 40W sodium vapour light at the suck back pump, close up

Plate 10: twin 80W sodium vapour street lights over camp parking lot.

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