FINAL REPORT

Castle Peak Power Company Limited

EIA of the Proposed 6000MW Thermal Power Station at Black Point: *Key Issue Assessment*

Solid By-Products Study

September 1993

ERM Hong Kong
10 & 11/F Hecny Tower
9 Chatham Road, Tsimshatsui
Kowloon, Hong Kong
Telephone 722 0292 (11/F)
Telephone 367 0378 (10/F)
Facsimile 723 5660

ERM

FINAL REPORT

Castle Peak Power Company Limited

EIA of the Proposed 6000MW Thermal Power Station at Black Point: *Key Issue Assessment*

Solid By-Products

September 1993

Project No. C1036

For and on behalf of ERM Hong Kong
Approved by: A M Lawton
Position: PROJECT MANAGER
Date: 10th September 1993

CONTENTS

ANNEXES

ANNEX A	-	*ANNUAL AND CUMULATIVE RAW MATERIAL CONSUMPTION AND BY-PRODUCT ARISINGS SCENARIO I*
ANNEX B	-	*ANNUAL AND CUMULATIVE RAW MATERIAL CONSUMPTION AND BY-PRODUCT ARISINGS SCENARIO II*
ANNEX C	-	*PFA UTILISATION - CLP 'ASH MARKETING' PUBLICATIONS*
ANNEX D	-	*AERIAL PHOTOGRAPHS OF POTENTIAL DISPOSAL FACILITIES*
ANNEX E	-	*RESPONSE TO COMMENTS ON EIA FOR THE LTPS AT BLACK POINT SOLID BY-PRODUCTS KEY ISSUE REPORT*
ANNEX F	-	*SOLID BY-PRODUCTS KIR RESPONSE TO COMMENTS - EPD CONSOLIDATED COMMENTS ANNEX TO POSITION STATEMENT*

LIST OF FIGURES

EXECUTIVE SUMMARY

OBJECTIVES

The aim of study has been to first quantify and then examine in respect of technical practicality, economic feasibility and environmental impact the practical options for the utilisation or disposal of thermal power station (TPS) by-product arisings over a twenty year period of operation of the proposed 6000MW LTPS at Black Point.

SCOPE

The Key Issue Assessment (KIA) includes consideration of coal combustion by-products; pulverised fuel ash (PFA) and furnace bottom ash (FBA); and flue gas desulphurisation (FGD) by-products; FGD gypsum and wastewater treatment sludge. An FGD system will be required for any coal-fired units installed at the LTPS in accordance with the 'Best Practical Means' concept for the abatement of stack emissions. CLP are considering two principle types of FGD system; the Limestone/Gypsum process and the Seawater process.

Two firing scenario's at the LTPS have been assumed for the study:

Scenario I – eight coal fired units
Scenario II – four gas followed by four coal-fired units

APPROACH

The study has proceeded through the following stages for each by-product.

By-product Arisings

Arisings of by-products from both CLP's TPS's; Castle Peak and the LTPS; and HEC's TPS at Lamma Island have been projected over the period 1992-2016 on the basis of various forecasts of electricity demand growth.

Prevention

Technology options currently being considered by CLP or identified in a review of current worldwide practice may afford means whereby arisings of some by-products might be reduced or prevented entirely. Such options have been assessed where appropriate.

UTILISATION

Utilisation of by-products, where it can be shown to be technically feasible, is preferable to disposal provided economic and environmental implications are not significant. Benefits to the local environment and economy can be realised in the form of eliminating the need to dispose of large quantities of by-products and in the reduction of the cost and impact associated with the production and supply of conventional materials.

Utilisation options that have a steady continuous demand for by-products are preferred over those with intermittent demand since there would be less need for storage. Both direct utilisation and options requiring the further processing of by-products have been considered. Processing of solid by-products *requires manufacturing facilities and in this regard it is recommended that a site of 30–40 ha; is set aside in the Tuen Mun Port Development area, close to the major by–product producers, for one or more utilisation facility.*

DISPOSAL

By–products not immediately utilised will require storage or disposal. Further, utilisation schemes may fail and hence, adequate disposal capacity must be available to afford back–up for all arisings. Disposal of large quantities of by–products in dedicated landfills, quarries or lagoons will inevitably incur some level of environmental impact. Hence, development of new facilities should only proceed when required. Planning dates are indicated appropriate to the level of utilisation achieved by that date. A site search was initiated by CLP to identify potential disposal sites within a workable distance of the LTPS. Each has been assessed on the basis of engineering, economic and environmental criteria. Practical constraints currently exist to the use of each of the identified facilities and will require resolution. The identified sites found potentially suitable, their capacities and constraints are shown below.

Table 1
Potential Disposal Sites

Facility	*Capacity (Mm^3)*	*Constraints*
Tsang Tsui Lagoons		
– *Existing*	5.5	
– *Extended*	13	a. *BBC Radio Station*
		b. *PADS Development proposed for 2011*
Landfills		a. *All located in Castle Peak Firing Range*
– *LF1*	10	
– *LF2*	16	
– *LF4*	55	
Quarries		
– *Q1*	5	a. *Currently in use*
– *Q2*	4	b. *Use as Government Depot*

New lagoons sites have been rejected on environmental, economic and availability grounds.

In addition to specific sites the Consultants have considered:

- *Disposal at Sea; in Hong Kong or International Waters*
- *Use of Underground Caverns*
- *Codisposal*

BY-PRODUCT ARISINGS

Table 2 shows the quantities of by-products involved calculated on the most pessimistic, 'worst-case' basis for the four by-products.

Table 2
Worst Case By-Product Arisings (kte/yr)

By-Product	*CLP*			*HEC*	*Totals*			
	CPPS	*LTPS*		*Lamma*	*Annual*		*Cumulative (2016 kte)*	
		Scenario I	*Scenario II*		*Scenario I*	*Scenario II*	*Scenario I*	*Scenario II*
PFA	*1,400*	*1,820*	*910*	*650*	*3,870*	*2,960*	*66,000*	*54,000*
FBA	*150*	*200*	*100*	*170*	*520*	*420*	*9,000*	*8,000*
FGD Gypsum	*0*	*700*	*350*	*150*	*850*	*500*	*12,500*	*7,500*
Sludge	*0*	*65*	*33*	*15*	*80*	*48*	*1,420*	*720*

Up to 64 Mm^3/yr of towns water could be required as feed to the FGD system. Periodic use of heavy fuel oil may be made by CLP. During such periods ash arisings would be virtually eliminated whilst gypsum arisings could double.

PFA MANAGEMENT

PFA will continue to be produced regardless of firing scenario at the LTPS, both from Castle Peak and HEC's units.

Utilisation

Current and potential consumers of large quantities of PFA are summarised below:

(a) Building Materials

Currently about 240 kte/yr of PFA are utilised in the manufacture of cement clinker (160 kte/yr) or in concrete production. However, the only increase in the figures that can be expected is that from normal market growth in concrete use, (to about 360 kte/yr on average) unless there is active promotion by both the producers and Government.

Potential increases that will not significantly effect economics, technical quality and the environment have been identified that could result in the utilisation of over 50% of PFA produced by CLP in concrete alone. However, certain obstacles would need to be overcome:

- *Use in cement clinker manufacture is at capacity and is the major current user of PFA. Continued production should not be discouraged and account should be taken of the environmental benefits associated with the use of PFA when assessing the impact of clinker manufacturing at existing or new kilns.*
- *Increased availability of the appropriate grade of quality controlled ash for concrete production should be ensured by investment by the utilities or others in classification facilities.*

- *Consideration should be given to the mandatory specification of PFA in all concrete produced in Hong Kong at 15% of Total Cementitious Content (rising to 25% if appropriate).*
- *The utilisation of PFA should be encouraged by the removal of remaining restrictions on its use in concrete and the active promotion of its incorporation in concrete.*

Other potential options that could utilise large amounts of PFA in the building trade are in the manufacture of lightweight aggregate and autoclaved aerated concrete blocks (AACBs). However, capital investment in plant and development of markets would be necessary to enable these options to be realised.

(b) PFA in Municipal Landfills

PFA satisfies the basic requirements of an interleaving material, although its use would require some operational changes and trials to confirm acceptability. Potentially up to 400 kte/yr of PFA could be utilised at the two new landfills; WENT and SENT.

PFA also has potential for use with sewage, water treatment sludge or wastewater treatment sludges as an interleaving material after processing by the N-Viro process, or when mixed with bentonite as a lining or capping material.

(c) Reclamation

Currently about 100 kte/yr are used in site formation or reclamation. There is scope to increase this figure dramatically. If approval were given for the use of PFA as an underwater fill, all arisings that are not utilised elsewhere could potentially be used. Tsang Tsui lagoons could act as a storage facility until there is demand for an appropriate quantity. Harvesting of lagooned PFA can be affected without significant impacts. Cost of such fill would compare favourably with alternatives.

Disposal

Regardless of the utilisation rate achieved or firing scenario the continued use and extension of the lagoons at Tsang Tsui is the favoured disposal route since this puts off the time, maybe indefinitely, when new disposal facilities must be developed. Ranking of disposal options for PFA is broadly as follows:

- *Tsang Tsui, existing and extended, LF2, LF1 (or LF1 + LF2), LF4*

Disposal at sea, via dumping outside Hong Kong waters, should only be pursued when all other options are exhausted.

Conclusions

The study has shown that given a concerted and continuous effort on behalf of CLP and encouragement and regulation by Government the whole issue of PFA disposal could disappear and all arisings could be put to use to the benefit of the Territory, without giving rise to significant adverse impact.

FBA MANAGEMENT

FBA is a by-product of commercial value and currently all of CLP's FBA is used to manufacture concrete blocks.

Utilisation

(a) Concrete Blocks

FBA can be substituted for conventional aggregate in concrete blocks to economic and technical advantage. Current utilisation by Kin Ching Besser Company stands as 130 kte/yr however there is increasing competition in the market in the form of imported blocks. Increases in utilisation must be regarded as speculative and would likely require price subsidies by CLP and investment in further block manufacturing plant.

(b) Other Potential FBA Utilisation Options

FBA has significant potential for use as an aggregates replacement or, if combined with PFA, excess FBA could be co-utilised in reclamation or as interleaving material.

Disposal

Consideration has been given to ensure adequate secure disposal capacity for excess FBA that cannot be utilised, or that could accommodate all FBA were utilisation to fail.

Potential disposal options are linked closely to those selected for excess PFA arisings since, in most instances, it will be preferable to dispose of FBA in segregated areas of any PFA disposal facility rather than develop further new facilities.

Preferred disposal routes for excess FBA are ranked as follows for both Scenario I and II.

- *Separate area at Tsang Tsui - current licence capacity*
- *Separate area at Tsang Tsui - extended capacity*
- *Separate area at PFA Landfill*
- *Dedicated FBA Quarry disposal site*

Conclusions

All FBA arisings from CLP's facilities should be able to be beneficially utilised given appropriate planning and favourable market conditions. Adequate opportunity exists to develop disposal facilities for FBA that cannot be utilised, either within a separate area of a PFA facility or at a dedicated site.

FGD GYPSUM MANAGEMENT

The Limestone/Gypsum FGD process is the world's leading FGD system, principally because the by-product, gypsum, has commercial applications notably in the manufacture of wallboard. However, there is no significant gypsum market in Hong Kong. The strategy for management of FGD by-products therefore focuses first on avoiding their production.

Prevention

Arisings could be avoided by the incorporation of alternative technology or process configurations, via:

- *Re-dissolution of product gypsum in seawater and discharge to sea via the cooling water outfall.*
- *Use of one of two Seawater FGD systems that also result in gypsum being discharged as dissolved species to sea.*

Use of either of the above is dependent on proving the technical and commercial feasibility of the technology and on the impact to the marine environment (see the parallel Water Quality KIR). In the event that these conditions cannot be realised, then a FGD gypsum producing process would be adopted, necessitating a by-product management strategy.

Utilisation

(a) Export

Export of FGD gypsum arisings to a net importer of gypsum such as Japan has been considered. However, there are reservations to such a scheme on the basis of technical constraints, security and expense. A quantity of off-specification gypsum would still require disposal in Hong Kong (amounting to about 10% of arisings).

(b) Other Potential Utilisation Options

The study has investigated the potential for utilisation as follows:

- *wallboard manufacture;*
- *cement manufacture;*
- *fill material;*
- *artificial reefs.*

However, all require market development and cannot be said to be reliable management strategies at this time.

Disposal

Disposal routes for LTPS FGD gypsum were ranked as follows (for Scenarios I and II except where stated):

- *disposal at Sea via marine dumping in Hong Kong or International Waters.*
- *separate area at PFA Landfill (Scenario II only).*
- *quarry site Q1 or Q2*
- *temporary use of a separate area at Tsang Tsui (Scenario I).*

If Scenario I is adopted then arisings would commence in 1996 and immediate planning for back-up disposal facilities would be required. Landfill sites, all of which are in the firing range are not appropriate.

Conclusions

Utilisation potential for any FGD gypsum that might arise at the LTPS is not quantifiable. Export may be feasible but cannot be guaranteed, local markets would require development. The focus of the management strategy is prevention of arisings via discharge of dissolved gypsum to sea in preference to utilisation or disposal of solid gypsum.

WASTEWATER TREATMENT SLUDGE (WTS) MANAGEMENT

Wastewater treatment sludge arises from the treatment of the purge stream bled from the absorber of the Limestone/Gypsum FGD system to control the build up of soluble salts. The management strategy focuses primarily on prevention of arisings via FGD process configuration if viability can be proved and environmental impact is acceptable; namely:

- *Use of Seawater FGD*
- *Recycle of the untreated wastewater to the flue gas duct or as a PFA conditioner*
- *Recycle of the sludge in the furnace or FGD process*

If WTS were produced, it might be possible to reduce the quantity requiring special handling via separation of the inert solids and toxic contaminants in the effluent treatment plant.

Utilisation

WTS contains raised levels of certain toxic metals and can have a high COD, making it an unsuitable utilisation material in itself. Utilisation options identified involve incorporation with other by-products' provided it can be demonstrated that the chemical and physical properties of the principle or all by-products are not altered by the addition of the sludge components. Options that lock toxic species in a cementitious solid matrix are preferred. The Study considered:

- *Artificial Reef Construction*
- *Incorporation into the Manufacture of PFA Aggregate, AACBs, FBA concrete or with PFA in N-Viro soil for use as interleaving material*
- *Reclamation material*

Disposal

Potential disposal sites are closely linked to those for FGD gypsum. The sludge can be dewatered to a 25% solids filter cake or alternatively stabilised with cement or PFA and lime. Options considered include:

- *Codisposal with gypsum or off specification gypsum*
  - *dispersed amongst the gypsum;*
  - *within a separate area.*
- *Disposal of stabilised sludge*
  - *to another by-product facility;*
  - *to municipal landfill.*

In theory the WTS could be sent to the Chemical Waste Treatment Facility, but arisings could greatly exceed CWTF capacity and independent stabilisation by the utilities is preferred. The stabilised material could then also assumedly be disposed of the same way.

Conclusions

The Study recommends that the preferred management strategy, if feasible, be prevention of arisings of WTS via technology selection. If sludge does arise, it would best be stabilised on-site prior to utilisation or disposal.

OVERALL CONCLUSIONS

In respect of the four by-products considered the study has shown that given the institution of a number of recommendations, appropriate technology selection by CLP (if feasible), and favourable market conditions all by-product arisings could either be prevented or beneficially utilised.

It is however, unlikely that all by-products could be utilised as they arise and quite possible that substantial quantities would not be utilised at all. No suitable disposal routes are currently available. However, several suitable sites have been identified, but actions by Government are required to make these available. These disposal routes should not give rise to unacceptable environmental impact, but are not entirely without adverse impact. Hence, feasible utilisation that is not unduly onerous in respect of environmental impact or economic implications should be actively persued by CLP.

Electricity is a resource for all industries and residents in Hong Kong, and it is therefore not unreasonable to expect that all Hong Kong (through its representatives in Government) to actively encourage the beneficial utilisation of these by-products and thereby help preserve its environment. In light of the above we would suggest that Government, CLP and other concerned parties institute, where possible, the recommendations of this study.

EPD's Position

The Director of Environmental Protection has the following views on the FGD Process to be adopted and the management strategy for the solid by-product:

- *The limestone gypsum process is the preferred process option to the seawater scrubbing for the FGD system. Seawater scrubbing has a greater potential to result in a substantial increase in pollutant loads with little opportunities for appropriate mitigation measures.*

- *Any gypsum produced as a by-product of the limestone gypsum process should be treated as a usable resource and hence EPD would prefer any utilisation of gypsum as the long term management strategy.*

- *A further study should be carried out before the final approval is given to the coal-fired units to develop a management strategy for the FGD gypsum.*

1 INTRODUCTION

1.1 BACKGROUND TO THE KEY ISSUE ASSESSMENT

1.1.1 The Proposed Development

The Castle Peak Power Company Ltd (CAPCO), a joint venture of Exxon Energy Limited and China Light and Power Company Limited (CLP) proposes to develop a Large Thermal Power Station (LTPS) in Hong Kong to meet forecast growth in electricity demand during the late 1990s and beyond. The LTPS would ultimately provide up to 6000MW of electrical output. CLP will act on behalf of CAPCO as the Project Manager for the construction and operation of the LTPS. The Key Issue Assessments (KIAs) consider two firing scenarios:

- *Scenario I* comprising eight coal-fired units rated at 680MW - a total of 5440MW;

- *Scenario II* where the units installed would be a combination of natural gas fired combined cycle gas turbines (CCGTs) of 600MW and 680MW coal-fired units - based on four of each this would give a total of 5120MW.

A third possibility would be for the LTPS to ultimately comprise eight CCGTs, but this would depend on fuel availability. Regardless of scenario backup fuel would be oil. In addition, oil would be used to fire up to ten 'peak lopping' 100MW (nominal) open cycle gas turbines.

1.1.2 Project History

ERM Hong Kong (formerly ERL (Asia) Limited) were commissioned by CLP in November 1989 to lead a team of Consultants to undertake a Site Search Study[(1),(2)] for the LTPS which resulted in the selection of the site at Black Point based on a number of engineering, security, operational, environmental and economic criteria.

Following the Site Search ERM were commissioned to complete the detailed Environmental Impact Assessment (EIA) for the proposed LTPS. The draft Initial Assessment Report (IAR)[(3)] was submitted to Government in April 1991. The findings of the report were generally accepted as satisfactory with the exception of certain Key Issues which required further in depth study. Three Key Issue Studies were commissioned:

- Stack Emissions;
- Water Quality; and
- Solid By-Products.

(1) ERL (Asia) Ltd., *6000MW Thermal Power Station, Final Site Search Report*, for CLP (September 1990).

(2) ERL (Asia) Ltd., *6000MW Thermal Power Station, Executive Summary*, for CLP (September 1990).

(3) ERL (Asia) Ltd., *EIA of the Proposed 6000MW Thermal Power Station at Black Point, Draft Initial Assessment Report*, for CLP (April 1991).

The need for a Solid By-Products KIA arose out of practical and environmental concerns over the reuse or disposal of materials that arise as a result of coal combustion and the use of flue gas desulphurisation (FGD) technology.

1.2 THE SCOPE OF THE STUDY

1.2.1 Objectives

This Key Issue Report (KIR) details the findings of the Solid By-Products Key Issue Assessment (KIA) study which has broadly aimed to examine all the practical options available for the management of the by-products that could arise in significant quantities and recommend suitable long term disposal/utilisation strategies on the basis of engineering practicality, economic feasibility and environmental impact. Output of by-products from CLP's other coal-fired power station at Castle Peak (and that of the Territory as a whole) have also been considered where appropriate.

1.2.2 The By-Products

By-Products will only arise from operations at the LTPS involving coal-firing. Use of gas in CCGTs does not result in the production of significant quantities of solid by-products or wastes. The Key Issue Assessment includes consideration of:

- *Coal combustion by-products* comprising:
  - furnace bottom ash (FBA);
  - pulverised fuel ash (PFA).
- *Flue Gas Desulphurisation (FGD) by-products* that could arise from either of the sulphur dioxide (SO_2) abatement processes under active consideration by CLP in accordance with the 'Best Practical Means' (BPM) concept for abatement of stack emissions. These are the Limestone/Gypsum Process and the Seawater System. Possible by-products comprise:
  - gypsum;

  and potentially;

  - wastewater treatment sludge.

  Note that it is only the Limestone/Gypsum Process that would produce gypsum. The Seawater System relies on capturing the sulphur dioxide in aqueous form as sulphate anions, $(SO_4)^=$, and discharging the effluent directly to sea with the cooling water. (The parallel Water Quality KIA addresses the potential environmental impact of this and other major effluent discharges form the proposed LTPS.)

1.2.3 *The Approach*

The Study follows on from the preliminary assessment conducted for the IAR where the broad issues involved and many of the possible management options were identified. The IAR concluded that where possible the by-products should be put to beneficial use and that disposal was not the preferred strategy. This study has adhered to this hierarchy whilst also planning for the 'worse case' situation where beneficial utilisation is either not viable or market and or local regulatory conditions do not develop in a manner that allows further utilisation.

The approach adopted over the study has been along a number of paths:

- *Quantification of by-product arisings* over a twenty year period and their physical and chemical properties of relevance. This has involved consultations with CLP, LTPS design engineers, FGD system and raw material suppliers, the analysis of materials arising from CLP's Castle Peak Power Station (CPPS) and the modelling of LTPS operations and of the pathways of pollutants through the generating plant and associated processing technology.

- *Review* of current world wide practices and regulatory systems, past studies in Hong Kong and abroad and CLP's in-house research programmes. CLP have been actively considering options for utilisation and disposal of power station by-products for many years and are thus well informed. Their own views regarding strategy have been incorporated and assessed during the study where appropriate.

- *Identification of beneficial utilisation options* that have the potential to consume significant proportions of the by-products. Each option was first considered in the international context, in isolation from the LTPS, such that its suitability in respect of impact to the environment, engineering feasibility and economics could be adjudged. Potentially suitable options were then placed in the local context as regards environment, common practice and legislation, from which integrated long-term management strategies are developed. In general, options with a continuous demand are considered ahead of those of intermittent demand. Further, those options determined to be suitable, but presently not practiced in Hong Kong, or that are not currently sanctioned by Government were considered where the practical and/or environmental advantages are likely to be significant.

- *Quantification of utilisation potential.* The options identified have been analysed with respect to their likely consumption (where possible) and reliability as by-product outlets. Obstacles to development of given markets are identified. As when identifying the options, consultations were held with CLP, relevant Government departments, and potential consumers. The meetings also investigated how impediments or concerns might best be allayed.

- *Identification of disposal options and sites.* Disposal facilities will be necessary in the event that by-products cannot be reused or in the case of market failures. Potential disposal options which were, for the most part, identified in previous studies (CLP's in-house studies, Site Search Study, the IAR etc) have been assessed as to their suitability regarding engineering feasibility, economics and environmental implications on a generic basis in collaboration with Mouchel Asia Limited. For suitable options, potential sites have been identified that do not pose additional strain on already stretched existing facilities, and capacities estimated. Further, constraints to the use of these facilities, site specific engineering, environmental and economic issues, necessary development lead times, and any necessary Government decisions have been considered.

- *Recommendation of integrated twenty year management strategies.* Viable management options have been compiled, in consultation with CLP, into long-term strategies incorporating current Hong Kong practice and legislation and the need for a secure disposal route under the most pessimistic conditions. Further, those options determined to be suitable, but presently not practiced or that are not currently sanctioned by Government are also considered where the environmental advantages are likely to be significant.

1.3 THE STRUCTURE OF THE KEY ISSUE REPORT

In accordance with the complexity of the issues involved and since much of the background to the various management options has been discussed in previous reports from this or other studies, this KIR is organised such that it addresses unresolved, potentially sensitive and site specific issues rather than dwelling on already accepted practices. As such the body of the report only summarises the main issues involved with each management option and makes recommendations thereon. Where more detailed explanation is necessary the reader is referred to the relevant background and supporting documents or an Annex. Reference is made to the parallel Water Quality and Stack Emissions Key Issue Studies where necessary.

The report is organised as follows:

- *Section 2* describes the by-products, details their specifications and quantifies their arisings over a twenty year period from 1996 on the basis of projected low, high and most likely (mean) growth in electricity demand in the Territory.

- *Sections 3, 4, 5 and 6* discuss the beneficial utilisation, disposal options and integrated twenty year management strategies for PFA, FBA, Gypsum and Wastewater Treatment Sludge respectively.

- *Section 7* presents the conclusions and recommendations of the study and discusses the way forward.

- *The Appendices* present relevant background and supporting information including quantification of arisings, CLP ash marketing material and aerial photographs of potential disposal sites.

2 THE BY-PRODUCTS; ORIGIN, PROPERTIES AND QUANTITIES

2.1 INTRODUCTION

Electricity generation in thermal power plants inevitably produces substances that can give rise to environmental impact, be this to air or water quality or to the land environment in the form of landfill sites. Of the possible fuels, gas produces the least potentially polluting streams due to its purity, high calorific value and the thermal efficiency of the available generating technology. However, natural gas is also usually the most expensive fuel and has strategic values for use in other applications where it can be utilised directly, such as in domestic housing, transportation and industry.

Oil and coal share the disadvantage of having a sulphur content which can give rise to acidification of the environment or human health effects if not properly controlled. If abatement takes the form of FGD, this process leads to the production of large quantities of solid by-products that require an outlet; via utilisation or disposal. Such technology also produces wastewater streams contaminated with pollutants including trace amounts of certain toxic metals. Treatment of this effluent can further lead to the production of significant quantities of waste solids.

Coal is the least pure fossil fuel and combustion leaves an ash residue, both in the furnace bottom (as FBA) and entrained in the exhaust gases (as PFA). The latter is commonly removed from flue gases with electrostatic precipitators with an efficiency in excess of 99.5%.

The following sections summarise the likely arisings of each of the solid by-products based on CLP's estimations of electricity demand in Hong Kong[4] up to the year 2016; comprising twenty years of LTPS operation. Estimates of by-product arisings are given assuming low, high and most likely (average) growth forecasts and are derived from coal consumption estimates at the LTPS and where appropriate, CPPS and Hongkong Electric (HEC) generating units. Full details can be found in *Appendices A and B*.

2.1.1 *By-Product Origins*

(a) Fuel Ash

Coal is pulverised into a powder before it is burnt as fuel to generate electricity. Pulverised coal is fed into the boiler furnace in a stream of air. Non-combustible materials are left as ash which either falls to the bottom of the furnace where it sinters to form furnace bottom ash (FBA) or is carried through the furnace with the flue gases as particles. The particles are trapped in electrostatic precipitators (ESPs) and collected as pulverised fuel ash (PFA). *Figure 2.1(a)* shows a schematic diagram of the ash system. FBA is quenched, removed from the boilers, and passed to temporary storage facilities. PFA from the ESP's can be conditioned with water to aid handling or handled in slurrified or dry powder form.

(4) CLP Communication, G. Dunn (CLP) to T.Walsh (ERL), *Solid Waste Study, ref. GPD/FO76/91/GD*, (19 July 1991)

(b) *Flue Gas Desulphurisation (FGD) Systems*

The Hong Kong Government Environmental Protection Department (EPD) specify that FGD would be required for LTPS coal-fired units to reduce levels of sulphur dioxide (SO_2) emitted with the flue gases. CLP have assessed the various commercially available FGD systems and two different FGD systems are still being considered, both are wet scrubbing processes where SO_2 is absorbed by an alkaline scrubbing liquor.

(i) *The Limestone/Gypsum System*

This FGD system uses a limestone slurry to absorb flue gas SO_2 in a wet scrubber. The system is conventionally configured to produce various grades of gypsum (calcium sulphate dihydrate) or, alternatively, the gypsum could be dissolved in the cooling water and discharged from the seawater outfall provided this configuration could be shown to be feasible and no adverse impacts result (see the Water Quality KIA[5]). *Figure 2.1(a)* shows a schematic of the system incorporating the configuration options.

The system uses large amounts of water of the order of 100 m^3/unit/hour. Towns water is generally used, particularly if product gypsum were destined for commercial outlets. CLP, however, are considering the use of recycled process water from elsewhere in the power plant (coal-stockyard runoff, boiler bottom water etc) or even to replace all or part of the fresh water demand with seawater. The latter would only be suitable if gypsum were destined for disposal or dissolution.

The limestone/gypsum system in its conventional configuration produces two solid by-products; FGD gypsum and much less significant quantities of wastewater treatment sludge. The sludge will arise should treatment of the purge water bled from the system be carried out. This water is bled to control the build up of soluble salts including chloride and other contaminants in the system and product. The purge stream is typically taken from the gypsum dewatering plant and is passed to a wastewater treatment plant from which it is discharged to sea after treatment.

(ii) *Seawater FGD*

These also use a wet scrubber to absorb SO_2, but the absorbent is the alkaline seawater used for cooling, supplemented by quantities of lime. Sulphur dioxide is removed from the system as gypsum (calcium sulphate) in solution with the cooling water return. Both calcium and sulphate ions are major natural constituents of seawater. Two processes are being considered:

- *The Flakt Seawater-with-Lime process* uses a substantial proportion of the condenser seawater flow to scrub the flue gases, utilising the natural alkalinity of the seawater. The seawater leaves the scrubber strongly acidic. Lime slurry and the remaining condenser seawater are added to the effluent in large aeration basins to adjust the pH of the acidic scrubbing liquor back to a value near to that of ordinary seawater and oxidise any sulphite to sulphate (*Figure 2.1(b)*).

(5) ERL (Asia) *"EIA of LTPS at Black Point, Water Quality KIR"* for CLP (June 1992).

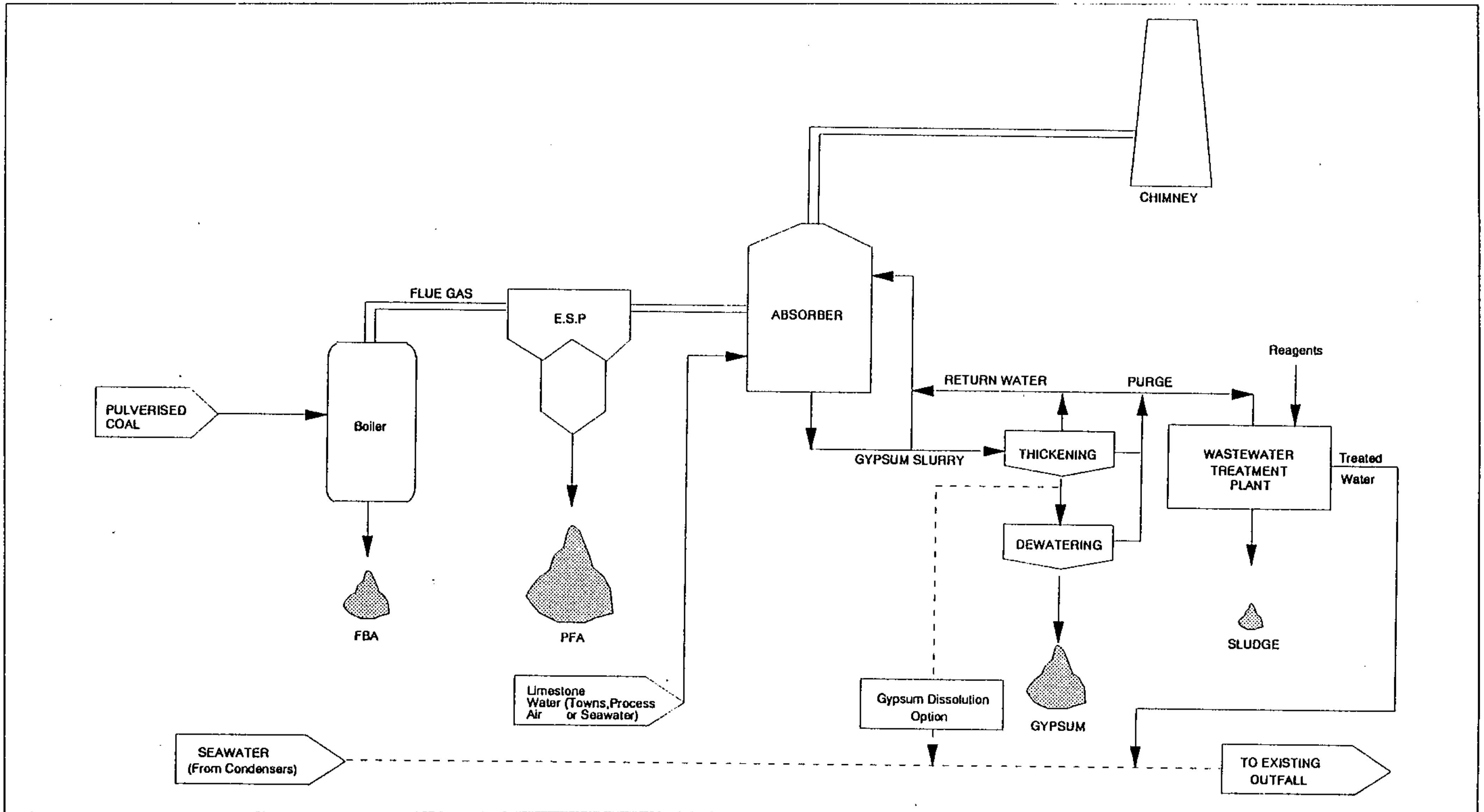


Figure 2.1(a) Schematic Ash and Limestone/Gypsum FGD System Flowsheet

ERM Hong Kong
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

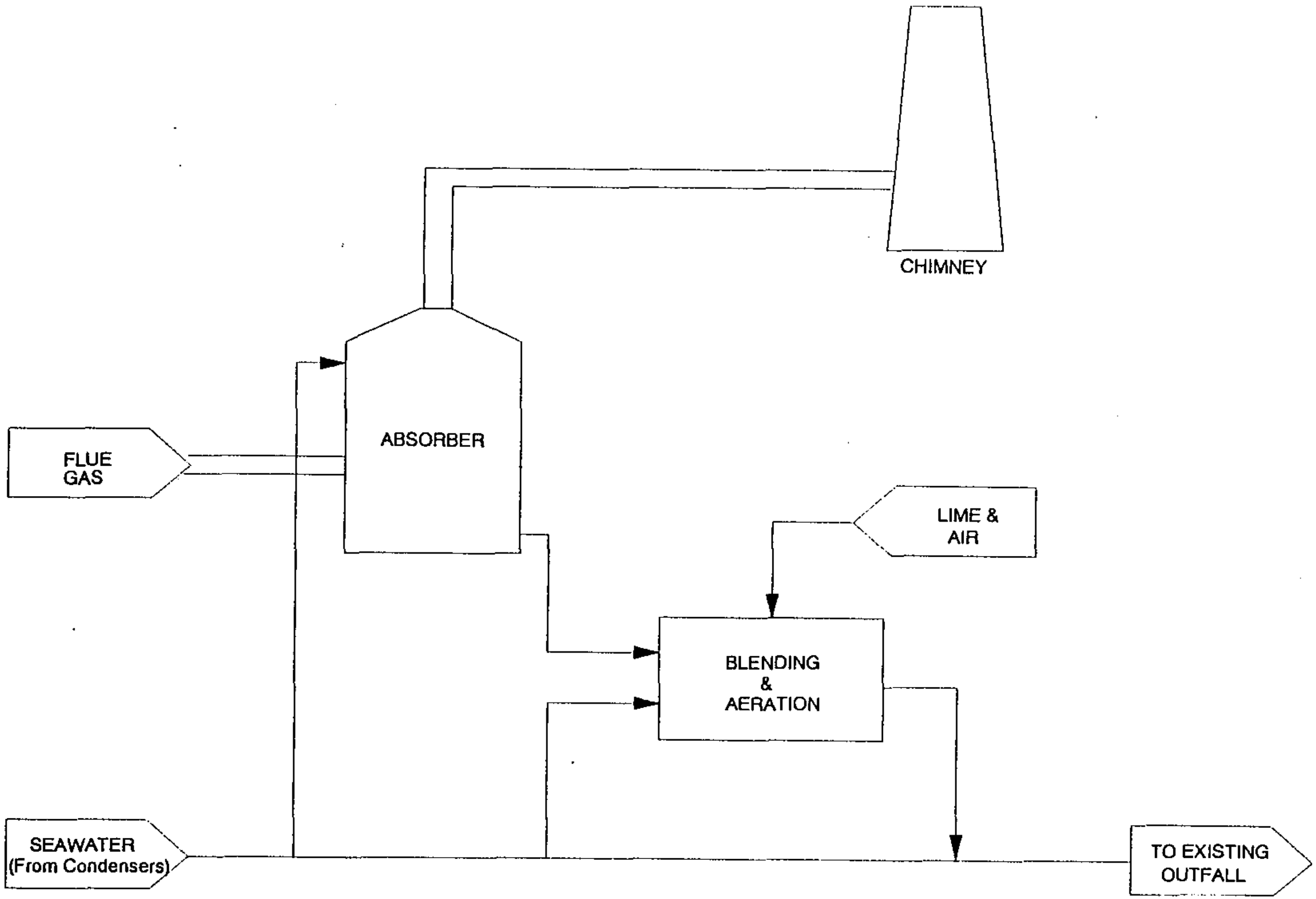


Figure 2.1(b) – Flakt Seawater FGD System Schematic

ERM Hong Kong
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong
ERM

- *The Bechtel Seawater process* differs in that only about 2% of condenser seawater flow is used for scrubbing the flue gas (significantly less than the Flakt system). The alkaline species in the seawater are regenerated by lime slurry addition within the recirculating loop of the absorber. Sulphur dioxide is removed from the system as calcium sulphate (gypsum) via a saturated bleed stream. The sulphate crystals rapidly dissolve on mixing with the remainder of the spent cooling water in the discharge outfall. A schematic of the system is shown in *Figure 2.1(c)*.

Neither of these systems produce any significant quantities of solid by-products in their standard configurations. Both could be fitted with a fresh water prescrubber to remove some of the PFA particles not caught in the ESPs and this acidic effluent treated giving rise to sludge. However, since the largest metal input originates from the lime the benefit of such equipment would be small. The potential marine environmental impact of Seawater FGD is assessed in the parallel Water Quality KIA.

2.2 FEEDSTOCKS AND REAGENTS

2.2.1 Specifications

Table 2.2(a) details the design data concerning feedstock specifications taken in the most part from CLP communications[(6)].

- *Coal* - all data from[(6)] assuming CPPS and LTPS burn, on average, coal with 16% ash content (as received). The study assumes coals ranging from 20% to 12% ash would be burnt. Current ash content is 11%.

- *Limestone* - all data from[(6)], based on the worst case of analyses of a number of high purity limestones from potential suppliers for the LTPS.

- *Lime* - derived from limestone data and factored up to account for molecular weights (as quicklime, CaO): $\frac{mg}{kg}(lime) = \frac{mg}{kg}(limestone) x \frac{100}{56}$

- *FGD Process Water* - all data from[(6)]. Specification represents likely worst case incorporating recycled run-off and other effluents.

- *Seawater* - all data from CLP's background water quality monitoring around Black Point, October 1990 to August 1991[(5)].

2.2.2 Feedstocks Consumption

(a) LTPS Commissioning Schedule for Scenarios I & II

The construction schedule for LTPS aims to have the first units operational by April 1996 under either firing scenario. *Table 2.2(b)* details the commissioning schedule assumed for the study. This differs slightly to that assumed in the IAR and is taken from[(4)]. Note the firing order for *Scenario II* could equally entail commissioning coal units prior to gas units or some other combination of 4 coal and 4 gas units. Commissioning years for individual units may vary slightly depending on the future electricity demand growth rate.

(6). CLP Memorandum, G. Dunn to J. Brunskill, *Water Quality KIR*, ref.GPD/PE/233/91/GD (27 June 1991)

Table 2.2(a)
FEEDSTOCK SPECIFICATIONS – LTPS at Black Point

Constituent	Coal	Limestone	Lime	FGD Process Water	Seawater
	% d.b. (ex H2O)	*Wt%*	*Wt%*	*mg/l*	*mg/l*
Carbon C	69.10	–	–	–	–
Hydrogen H	4.20	–	–	–	–
Sulphur S	1.10	–	–	–	–
Nitrogen N	1.60	–	–	–	–
Chlorine Cl	0.30	–	–	–	–
Oxygen O	6.20	–	–	–	–
Ash	17.50	–	–	–	–
	containing				
Calcium Ca	0.50	–	–	12.50	352.0
Iron Fe	0.60	–	–	1.00	1100.0
Aluminimum Al	2.00	–	–	1.00	944.0
Moisture H2O	12.00	–	–	–	–
CaCO3	–	> 90.0	–	–	–
CaO	–	–	> 90.0	–	–
SiO2	–	0.0 – 5.0	0.0 – 5.0	–	–
Al2O3	–	0.0 – 1.0	0.0 – 1.0	–	–
Fe2O3	–	0.0 – 1.0	0.0 – 1.0	–	–
MgO	–	0.0 – 1.0	0.0 – 1.0	–	–
SO4	–	–	–	–	2117.00
Trace constits	*mg/kg*	*mg/kg*	*mg/kg*	*mg/l*	*mg/l*
Phosphorus P	1000.00	100.00	178.57		0.08000
Flourine F	120.00	–	–	–	–
Bromine Br	20.00	–	–	–	–
Arsenic As	5.00	0.75	1.34	0.010	0.00083
Cadmium Cd	1.00	1.00	1.79	0.010	0.00006
Chromium Cr	10.00	10.00	17.86	0.010	0.00201
Copper Cu	20.00	3.00	5.36	0.020	0.00590
Mercury Hg	0.10	0.20	0.36	0.010	0.00100
Nickel Ni	20.00	5.00	8.93	0.100	0.00192
Lead Pb	10.00	1.00	1.79	0.050	0.00202
Antimony Sb	1.00	1.00	1.79	0.010	–
Selenium Se	1.00	0.50	0.89	0.010	0.00100
Zinc Zn	25.00	15.00	26.79	0.050	0.00684

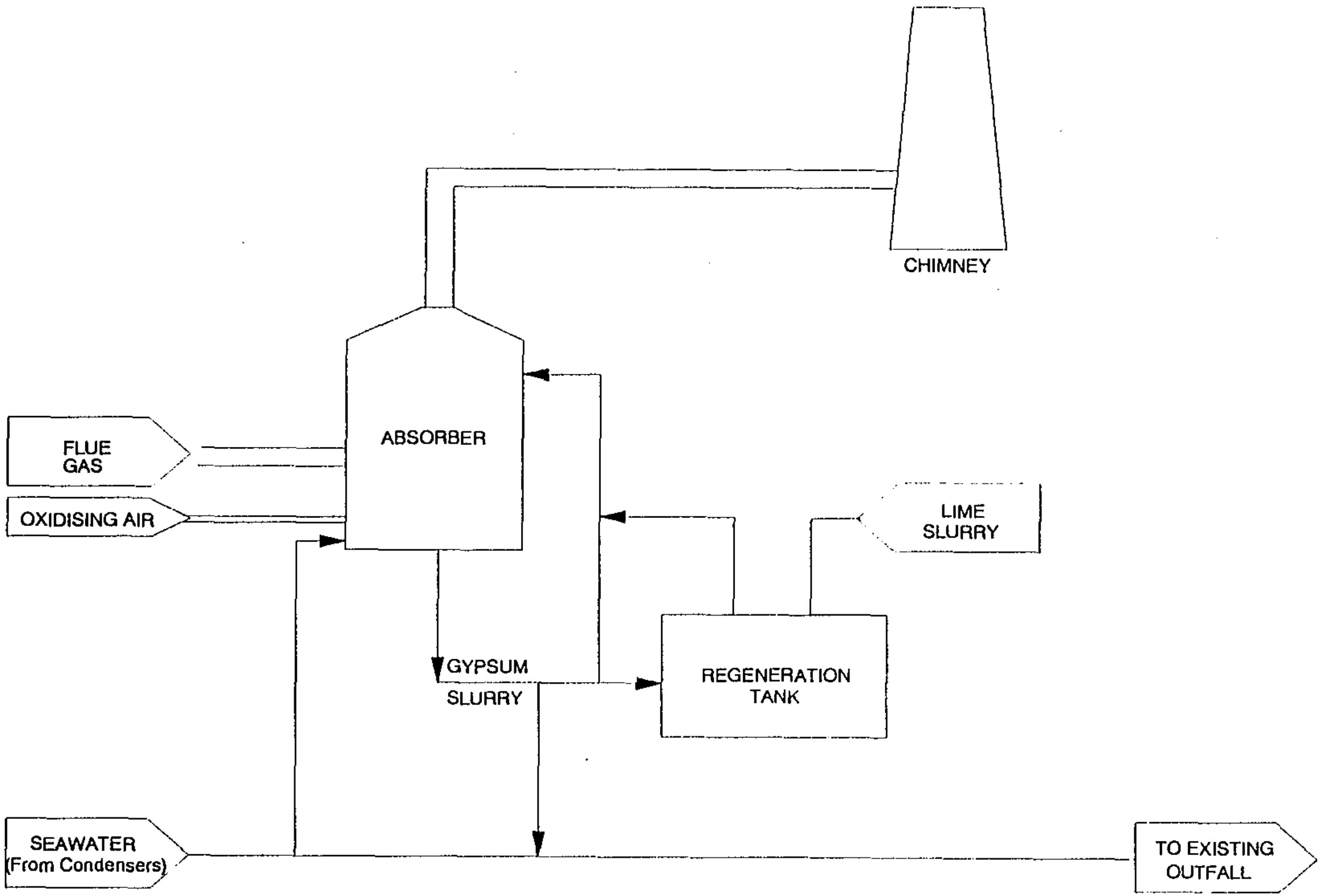


Figure 2.1(c) Bechtel Seawater FGD System Schematic

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Table 2.2(b) *LTPS Unit Commissioning Schedule*				
Year	Scenario I		Scenario II	
	Firing	Rating MW_e	Firing	Rating MW_e
1996	Coal	680	Gas	600
1997	Coal	680	Gas	600
1998				
1999				
2000	Coal	680	Gas	600
2001				
2002	Coal	680	Gas	600
2003				
2004	Coal	680	Coal	680
2005	Coal	680	Coal	680
2006				
2007	Coal	680	Coal	680
2008	Coal	680	Coal	680

Oil Firing

CLP have indicated that 3.5% Sulphur Heavy Fuel Oil (HFO) might be burnt in the LTPS boiler (coal) units under various operating scenarios, such as during market price fluctuations, shortages in coal supply, combustion stabilisation operations, start-up and emergency situations. The FGD system would again remove much of the SO_2 from the flue gases.

(b) Coal Consumption - Castle Peak A & B and LTPS at Black Point

Coal consumption at CLP's TPSs is taken from communication[4] where details of the basis can be found. It is basically a coal consumption forecast from CLP based upon three different growth rates in electricity demand:

- *Average* - uses a detailed load forecast for the years 1992 to 2002 and assumes an annual growth rate of 5% for years 2003 to 2010 and 4% from 2011 to 2016. PRC sales are accounted for, as is additional supply from two nuclear units at Daya Bay.

- *High* - growth rate is 1% (compound) higher than the average case.

- *Low* - growth rate is 1% (compound) lower than the average case.

In the current study it has been assumed that Castle Peak and Black Point will be used to capacity once the forecast electricity demand reaches such levels. This will make arisings forecasts err on the conservative side. Any further generation units required by CLP are not considered as these are not part of the current study and their fuel source is obviously uncertain.
Figures 2.2(a) - (d) show annual and cumulative coal burn at CLP's two TPSs under the two firing scenarios for the LTPS. Detailed figures can be found in *Appendices A and B*.

(c) *Limestone Consumption – Limestone/Gypsum FGD for coal units at the LTPS at Black Point*

Limestone is used as the SO_2 absorbing reagent in the limestone/gypsum FGD system. The quality as well as the quantity consumed determines the quantity of gypsum by-product that would be produced.

Limestone consumption is determined based on the coal burn figures given above, the sulphur content of the coal and the chemical compositions of the feed limestone and intended product gypsum (see *Section 2.5*). It is assumed that 90% of the sulphur in the coal will be captured by the FGD system.

The worst case sulphur content of the coal is 1% by weight (a.r.b.). Hence, the quantity of sulphur collected per tonne of coal burnt is given by:

$$1 \times 0.01 \times 0.9 = \frac{.009\,te(S)}{te(coal)}$$

The active limestone required annually is given by:

$$\frac{te(activeCaCO_3)}{te(coal)} = \frac{te(S)}{te(coal)} \times \frac{100}{32}$$

where 100 and 32 are the molecular weights of calcium carbonate, $CaCO_3$, and sulphur respectively. This figure represents only the active components. Some $CaCO_3$ remains unreacted and there is an inert component in the raw limestone which must also be accounted for.

The calculation for an FGD system producing the high grade gypsum CLP envisage is as follows:

$$\frac{te(totCaCO_3reqd.)}{te(coal)} = \frac{te(activeCaCO_3)}{te(coal)} \times \frac{\left(83.5 \times \frac{100}{172} + 1.3 \times \frac{100}{129}\right)}{\left(83.5 \times \frac{100}{172} + 1.3 \times \frac{100}{129} + 2.5\right)}$$

where 83.5, 1.3 and 2.5 are the compositions of dihydrate, sulphite and carbonate in the gypsum and 172, 129 and 100 their respective molecular weights.

Hence the total quality of limestone required is (at 5% inerts):

$$\frac{te(limestone)}{te(coal)} = \frac{te(totCaCO_3reqd.)}{te(coal)} \times \frac{1}{0.95}$$

These calculations give a figure of 31.1 kg(lmst.)/te(coal) for high grade gypsum. Detailed figures of annual and cumulative projections can be found in *Appendices A and B* for *Scenario I & II*, and are shown graphically in *Figures 2.2(e)–(h)*.

Figure 2.2a – Annual CLP Coal Burn – SCENARIO I

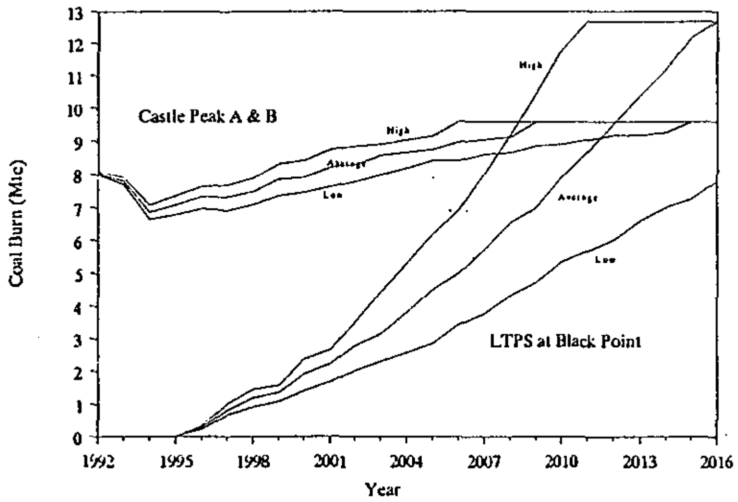


Figure 2.2c – Annual CLP Coal Burn – SCENARIO II

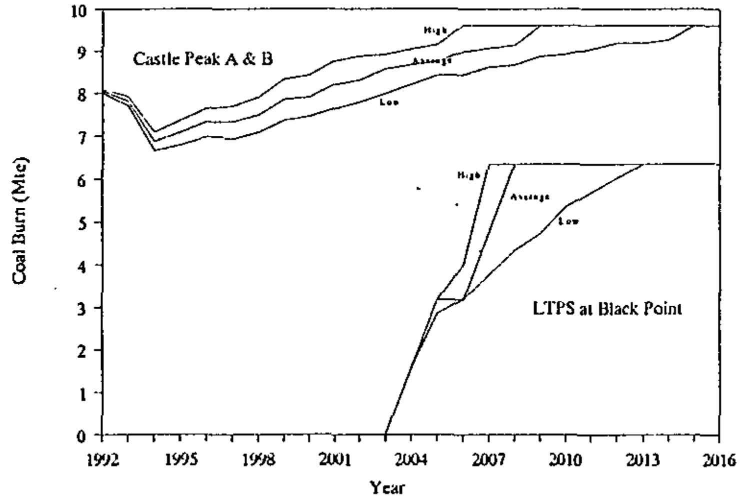


Figure 2.2b – Cumulative CLP Coal Burn – SCENARIO I

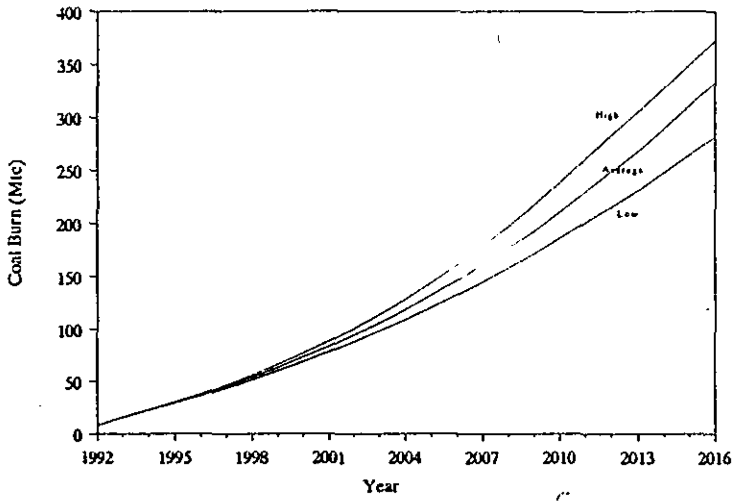


Figure 2.2d – Cumulative CLP Coal Burn – SCENARIO II

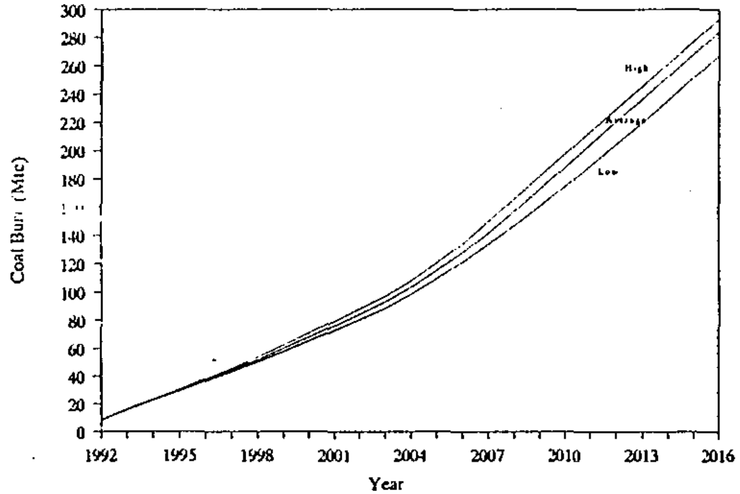


Figure 2.2(a–d)

CLP Coal Burn

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Figure 2.2e – Annual CLP Limestone Consumption, Limestone/Gypsum FGD – SCENARIO I

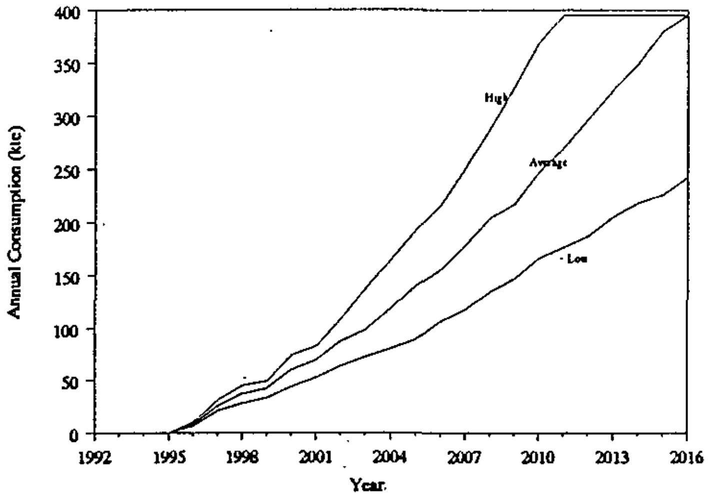


Figure 2.2g – Annual CLP Limestone Consumption, Limestone/Gypsum FGD – SCENARIO II

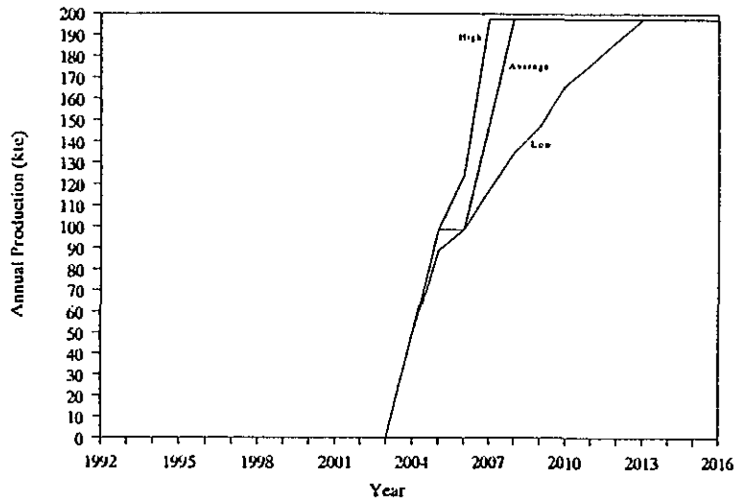


Figure 2.2f – Cumulative CLP Limestone Consumption, Limestone/Gypsum FGD – SCENARIO I

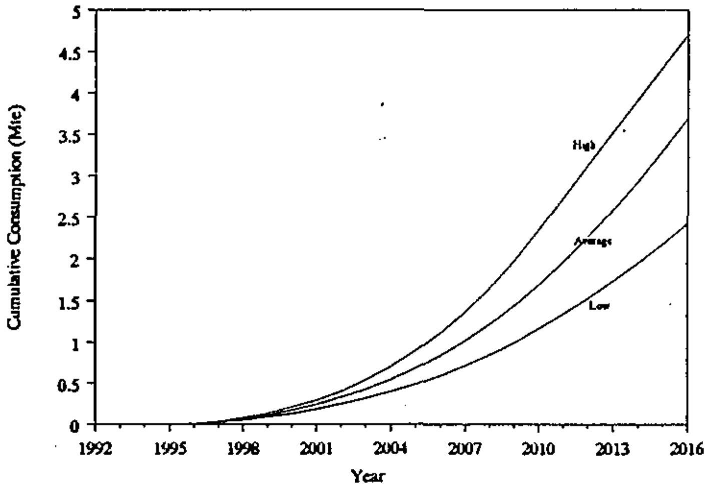


Figure 2.2h – Cumulative CLP Limestone Consumption, Limestone/Gypsum FGD – SCENARIO II

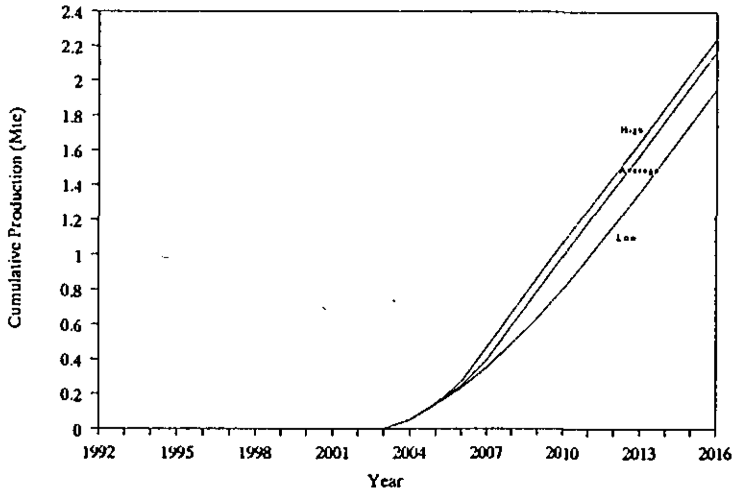


Figure 2.2(e–h)

CLP Limestone Consumption, Limestone/Gypsum FGD

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

(d) *Lime Consumption – Seawater FGD for coal units at the LTPS at Black Point*

Seawater FGD systems also rely on the absorption of acidic SO_2 in the flue gas by an alkaline scrubbing media. Seawater itself is alkaline and absorbs some SO_2, however its alkalinity needs to be buffered by addition of further reagent. The two systems commercially available from Flakt and Bechtel, differ in process configuration, but both use lime as opposed to limestone as a reagent (due to its greater activity).

Lime consumption for these systems has been calculated on the basis that all sulphur absorption is at the expense of the lime, as the worst case. Some sulphur dioxide will be absorbed directly by the seawater, but this will depend on detailed system design and seasonal variations in seawater alkalinity.

Lime consumption on the above basis is calculated as for limestone, but incorporating the appropriate molecular weights. 17.2 kg (lime)/te(coal) would be required. *Figures 2.2(i)–(l)* show the annual and cumulative consumption curves. Detailed figures of annual and cumulative projections can be found in *Appendices A and B* for *Scenarios I & II.*

(e) *Water Consumption*

The Seawater FGD systems make use of the cooling water at the power station. Only small amounts of fresh water would usually be used for lime slaking, however, even this might be replaced by recycled process water. The conventional limestone/gypsum system would use around 100 m^3/hr/unit of towns or process water. This would amount to about 340 kg (water)/te (coal) or about 5Mm^3/yr (*Scenario I*) or 2.5Mm^3/yr (*Scenario II*).

2.3 *PULVERISED FUEL ASH (PFA)*

2.3.1 *Specifications and Characteristics*

The individual particles of PFA vary in size and shape, but they are predominantly spherical varying in size from 1 to 200 microns, which is comparable to a range from fine silt to fine sand. Small, hollow, glassy spheres are also usually present, together with other crystalline matter, as well as a varying amount of carbon. Other properties of PFA, which are important for this study are that:

- it is lightweight
- it combines easily with free lime
- in bulk form, it absorbs water
- it has pozzolanic properties

(a) *Chemical, Physical and Engineering Properties*

The composition of pulverised fuel ash varies widely depending on the composition of the coal from which it is derived, boiler firing techniques and ash collection equipment. It characteristically contains large quantities of silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3) and smaller quantities of other oxides such as CaO, MgO, and P_2O_5.

Details of chemical, physical and engineering properties of PFA from CPPS are presented in a report on the geotechnical properties of PFA[7]. Chemical properties are summarised in *Table 2.3(a)* and physical/geotechnical properties in *Table 2.3(b)*.

(b) *Trace Elements*

Coal being a naturally occurring mineral, contains a wide range of trace contaminants, the most abundant of which are silicon, iron and aluminum. Other elements include the environmentally sensitive metals; arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. The worst case concentrations of these elements in coals for the proposed LTPS are shown in *Table 2.2(a)*.

These contaminants may be present in the coal in either elemental form or in combination with, for example, oxygen. The degree to which they are lost directly to the environment following combustion depends on the volatility of the species formed. In the case of mercury, which is converted to gaseous species, this loss is virtually total, leaving little in the ash. Whereas non–volatile elements such as nickel, which would be almost entirely in the solid phase under the furnace conditions, would be retained in the furnace bottom ash and fly ash.

Many elements are, however, only partially volatilised during combustion. While elements or their species are volatilised at the highest temperatures of the combustion process, there is subsequent condensation on the fly ash matrix as the temperature reduces from the maximum encountered in the furnace. In the case of least volatile species, condensation is rapid and is essentially complete before the flue gas reaches the ESPs. *Table 2.3(c)* shows typical metal concentrations in PFA.

(7) Binnie Consultants Limited, "*The Geotechnical Properties of PFA*," for CLP (1990).

Figure 2.2i – Annual CLP Lime Consumption, Seawater FGD – SCENARIO I

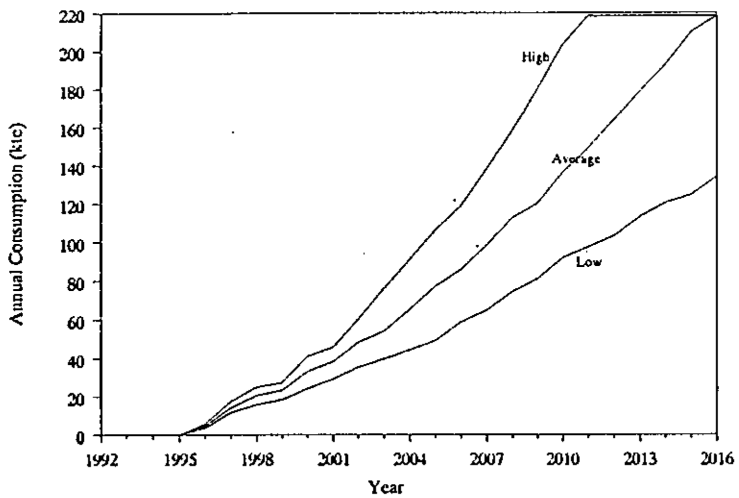


Figure 2.2k – Annual CLP Lime Consumption, Seawater FGD – SCENARIO II

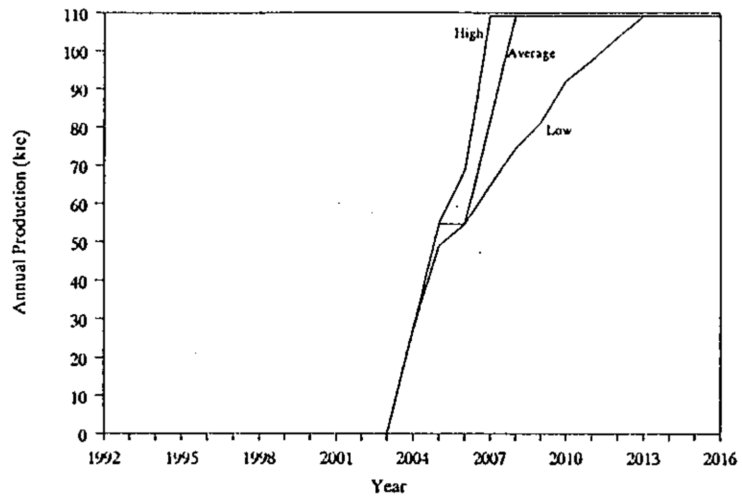


Figure 2.2j – Cumulative CLP Lime Consumption, Seawater FGD – SCENARIO I

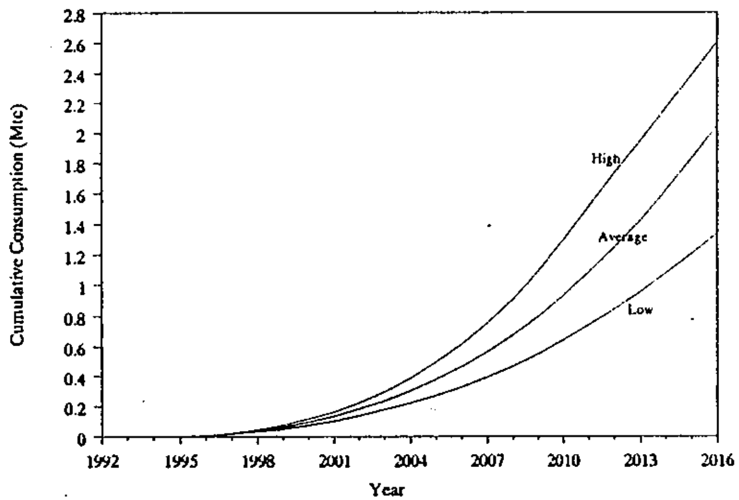


Figure 2.2l – Cumulative CLP Lime Consumption, Seawater FGD – SCENARIO II

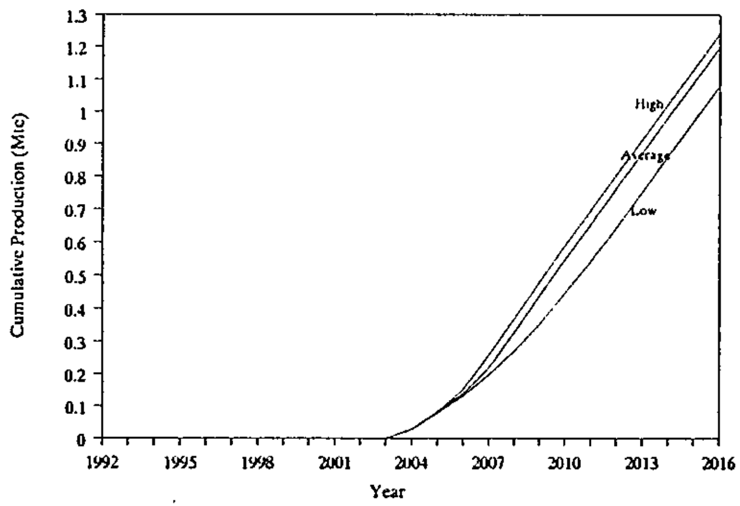


Figure 2.2(i–l)

CLP Lime Consumption, Seawater FGD

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Table 2.3(a)
Chemical Properties of PFA from CPPS

Constituent (as oxides unless stated)	**Typical Range** **% by W/W**
Silicon	38 - 77
Aluminum	14 - 46
Iron	1.2 - 17
Calcium	0.03 - 15.6
Magnesium	0.02 - 2.6
Potassium	0.13 - 2.4
Sodium	0.03 - 1.2
Titanium	0.6 - 1.9
Sulphate	0.06 - 0.75
Elemental Carbon	3.6 - 8.0

Table 2.3(b)
Physical and Geotechnical Properties of PFA

Physical Properties	**Physical Property**	**Conditioned PFA**[a]	**Lagooned PFA**[b]
	Particle size distribution		
	% Gravel	0	0
	% Sand	35	30
	% Silt	57	60
	% Clay	8	10
	Specify gravity	2.25	2.24
Geotechnical Properties	**Geotechnical Property**	**Conditioned PFA**	**Lagooned PFA**
	Dry Density (te/m^3) Standard Proctor Max	1.25	1.21
	Moisture Content % Optimum for Standard Proctor	27	30
	In-situ Bulk Density (te/m^3)	1.55 (compacted)	1.00 (settled)
	Effective Strength		
	C' (kN/m^2)	20[c], O[d]	14[c], O[d]
	ϕ (Degrees)	34[c], 32[d]	34[c], 32[d]
	Modulus of Compressibility M_v (m^2/MN)	not recorded	0.17
	Coefficient of Permeability P (m/s) at 95% standard Proctor Maximum Density	5 x 10^{-6}	1 x 10^{-6}
	California Bearing Ratio (%) at 100% standard proctor maximum dry density	15	15

Note:
a) Conditioned PFA means fresh dry PFA stored in silos, to which sufficient water is added to aid transport and handling as a bulk fill material.
b) Lagooned PFA means settled PFA at Tsang Tsui PFA Lagoon which is transported as a slurry by pipeline.
c) Typical value measured
d) Appropriate lower bound value measured.

Table 2.3(c)
Trace Elements in PFA in Hong Kong and Worldwide

Element		Castle Peak[8],[9]	Lamma (HEC)[10] (ppm)	Worldwide[11]
Arsenic	As	10 - 89	40	2 - 1,700
Cadmium	Cd	0.1 - 0.8	2	0.1 - 250
Chromium	Cr	18 - 113	-	5 - 7,400
Copper	Cu	10 - 56	10	16 - 3,020
Mercury	Hg	<1	4	0.01 - 22
Nickel	Ni	16 - 30	-	1.8 - 8,000
Lead	Pb	4 - 47	10	3.1 - 1,600
Antimony	Sb	-	8	0.8 - 1,000
Selenium	Se	<1 - 7	10	0.05 - 760
Zinc	Zn	46 - 122	80	14 - 13,000

(c) *Leachate Analyses*

As a result of the vaporisation - condensation process some elements are concentrated on the surfaces of the ash particles, a process known as enrichment. This is particularly relevant to smaller ash particles which have a higher specific surface area. *Table 2.3(c)* shows the bulk concentrations of sensitive trace elements, however, there is frequently a higher concentration of trace elements on the surfaces of PFA compared with the interiors and hence greater potential for leaching exists. A report[12] by the International Energy Agency defines classes of trace elements according to their vaporisation properties during combustion, the elements considered here are shown in their classes below:

I - non-vaporisation - (Cr), (Ni)
II - vaporisation - condensation - As, Cd, Cu, (Ni), Pb, Sb, Se, Zn
I/II - intermediate - Cr, (Cu), Ni, (Se)
III - vaporisation - non-condensation - Hg

Note: Elements shown in brackets where so classified by other researchers.

It is those metals in Class II or I/II that have the greatest leaching potential. For example, arsenic, chromium and lead have been shown to be about three times more concentrated on the surface of PFA particles than in the bulk with cadmium reaching up to 30 times[6] more concentrated.

(8) Aspinwall & Company *"Privatisation of SENT Landfill, Results of PFA Leaching Trials,"* for EPD (Agreement No.CE 79/90) (December 1991).

(9) L.G. Mouchel & Partners (Asia) and ERL (Asia) Ltd *"Castle Peak Power Stations, PFA Disposal, Lagoon at Tsang Tsui and Associated Works, Environmental Impact Assessment"* for CLP (1985).

(10) Binnie & Partners (HK) *"Ash Management Study, Environmental Impact Assessment, Initial Assessment Report"* for HEC (November 1988).

(11) Sloot, Vander, H.A. etal *"Leaching of Trace Elements from 'Coal Ash' and Coal Ash Products" Wastes in the Ocean Volume 4, Wiley (1985).*

(12) IEA Coal Research *"Trace Elements from Coal Combustion: Emissions"* 1EACR/01 (June 1987).

Table 2.3(d) and (e) show results of extensive leachate tests carried out on behalf of Government with CLP's PFA using both fresh and lagooned samples with seawater and deionised water leaching media. Results are taken from[8] and are averaged. Testing was designed to assess the acceptability of using lagooned or fresh PFA as underwater fill at the SENT landfill and trials were based on an accepted procedure used to determine leachate characteristics at landfills. Three types of PFA were used;

- *Fresh PFA*; composite samples of PFA direct from the ESP.
- *Acidic PFA*; sample of fresh PFA giving the most acidic leachate as a worst case.
- *Lagooned PFA*; representive sample of PFA from Tsang Tsui lagoons.

The tests used successive "bed volumes" (equal to the porosity) to measure the rinsing effect of successive bed volumes on quantities of metals leached. Full details of the test procedures are given in[8].

Leachate analyses from CLP's PFA disposal facilities are summarised in *Table 2.3(f)* for on-land and lagoon facilities respectively.

Table 2.3(f)
Trace Elements at CLP PFA Disposal Facilities

Element (Total recoverable metals in ppm)		Siu Lang Shui Leachate[13]	Tsang Tsui[14]	
			Inside Lagoon	Outside Lagoon Seawall
Arsenic	As	n.d.	0.005	n.d.
Cadmium	Cd	n.d.	0.00016	0.00009
Chromium	Cr	0.01	-	-
Copper	Cu	-	0.0035	0.0036
Mercury	Hg	-	-	-
Nickel	Ni	-	-	-
Lead	Pb	n.d.	0.0025	0.0023
Antimony	Sb	-	-	-
Selenium	Se	n.d.	0.36	n.d.
Zinc	Zn	-	0.015	0.007

n.d. = not detected

The metals in the area outside the lagoon do not necessarily original from the lagoon itself.

(13) CLP Scientific and Technical Services Department, *Environmental Monitoring of Drainage Water from Siu Lang Shui Coal Ash Disposal Sites,* (July 1988 – January 1989) Data derived from samples of drainage water percolating through ash lagoons. Average of monthly samples at two sites over 6–months period.

(14) CLP Scientific and Technical Services Department, *Trace Metal Monitoring of Seawater inside the Tsang Tsui Ash Lagoons, 1989.*

Table 2.3(d)
Leachate Test Results with Seawater

PFA		Bed Volume	pH	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Selenium (Se)	Zinc (Zn)
Fresh	Composite 1	1	9.8	<0.002	0.002	0.800	<0.075	<0.025	0.003	0.06	0.05
		2	9.9	0.006	0.004	2.300	<0.075	<0.025	0.002	0.003	0.02
		3	9.4	0.006	0.003	1.166	<0.075	<0.025	0.002	0.004	0.02
		4 - 13	9.1	<0.002	0.002	0.200	<0.075	<0.025	0.002	0.003	0.02
	Composite 2	1	10.8	<0.002	0.005	1.200	<0.075	<0.025	0.007	0.140	0.03
		2	10.7	0.007	0.004	2.200	<0.075	<0.025	0.004	0.005	0.02
		3	9.9	0.008	0.007	1.670	<0.075	<0.025	0.006	0.007	0.03
		4 - 13	10.7	0.010	0.003	0.330	<0.075	<0.025	0.002	0.028	0.03
	Acidic	1	7.8	0.030	0.030	0.500	<0.075	0.3	0.004	0.060	0.08
		2	8.5	0.070	0.005	0.500	<0.075	<0.025	0.004	0.260	0.03
		3	8.4	0.090	0.005	0.170	<0.075	<0.025	0.003	0.270	0.02
		4 - 13	8.4	0.240	0.004	0.020	<0.075	<0.025	0.003	0.080	0.03
Lagooned		1	9.0	<0.002	0.004	0.300	<0.075	<0.025	0.003	0.005	0.02
		2	8.8	<0.002	0.003	0.300	<0.075	<0.025	0.004	0.004	0.03
		3	8.8	0.002	0.004	0.260	<0.075	<0.025	0.006	0.005	0.02
		4 - 13	10.5	0.003	0.002	0.060	<0.075	<0.025	0.003	0.014	0.02
Blank		1	ND	ND	<0.001	ND	<0.075	<0.025	0.003	ND	<0.01
		2	ND	ND	<0.001	ND	<0.075	<0.025	0.004	ND	<0.01
		3	ND	<0.002	<0.001	ND	<0.075	<0.025	0.004	<0.002	<0.01
		4 - 13	ND	<0.002	<0.001	ND	<0.075	<0.025	0.004	<0.002	<0.01

Notes : ND = not detected
All units in mg/l (except pH)

Table 2.3(e)
Leachate Test Results with Deionised Water

PFA		Bed Volume	pH	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Selenium (Se)	Zinc (Zn)
Fresh	Composite 1	1	11.1	<0.002	<0.002	0.330	<0.3	<0.1	<0.001	0.040	<0.05
		2	12.1	<0.002	<0.002	0.022	<0.3	<0.1	<0.001	0.003	<0.05
		3	11.9	<0.002	<0.002	0.046	<0.3	0.1	<0.001	0.003	<0.05
		4 – 13	11.7	<0.002	<0.002	0.090	<0.3	<0.1	<0.001	0.003	<0.05
	Acidic	1	8.7	0.004	0.015	0.230	<0.3	0.3	<0.001	0.077	<0.05
		2	9.2	0.003	0.003	0.160	<0.3	<0.1	<0.001	0.060	<0.05
		3	9.3	0.003	0.015	0.097	<0.3	<0.1	<0.001	0.060	<0.05
		4 – 13	9.2	0.005	0.003	0.018	<0.3	<0.1	0.001	0.080	<0.05
Lagooned		1	9.7	<0.002	0.010	0.350	<0.3	<0.1	0.007	0.003	0.06
		2	9.7	<0.002	0.010	0.180	<0.3	<0.1	0.010	<0.002	0.07
		3	9.3	<0.002	0.006	0.100	<0.3	<0.1	0.010	<0.002	0.05
		4 – 13	10.5	<0.002	<0.002	0.030	<0.3	0.1	0.005	<0.002	<0.05
Blank		1	–	<0.002	<0.002	ND	<0.3	<0.1	0.001	<0.002	<0.05
		2	–	<0.002	<0.002	ND	<0.3	<0.1	<0.001	<0.002	<0.05
		3	–	<0.002	<0.002	ND	<0.3	<0.1	<0.001	<0.002	<0.05
		4 – 13	–	<0.002	<0.002	ND	<0.3	<0.1	<0.001	<0.002	<0.05

Notes : ND = not detected
All units in mg/l (except pH)

2.3.2 *PFA Arisings*

Pulverised fuel ash (PFA) arisings at the LTPS and CPPS are determined based on the coal burn figures given in *Section 2.2* and the assumed average ash content of the coal (16%). It is assumed that 90% of the ash produced will be PFA, based on Castle Peak experience.

The PFA produced annually is given by:

$$\frac{te}{yr}(PFA) = \frac{te}{yr}(coal) \times 0.16 \times 0.9$$

Figure 2.3(a)–(d) show annual and cumulative projections at CLP's TPSs under Scenarios I & II. Detailed figures can be found in *Appendices A and B.*

The only other major producer of PFA in the Territory is Hong Kong Electric Company (HEC) who currently fire 5 units (3 at 250 and 2 at 350 MW) coal–fired units on Lamma Island. A further 3 x 350 MW are planned to be installed within the study period. *Figures 2.3(e) and (f)* show the likely annual and cumulative production based on data supplied by EPD[15].

Note CPPS currently produces about 1 Mte/yr of PFA of which about 340 kte/yr are beneficially utilised. HEC are believed to currently export much of their PFA to the PRC for use in land restoration and the building trade.

The effect of oil firing at the LTPS would be to virtually eliminate arisings of ash for the periods it was fired, reducing the overall arisings from those shown slightly. Oil contains quantities of inert materials but the arisings at the ESP would not be significant in the context of PFA arisings.

2.4 *FURNACE BOTTOM ASH (FBA)*

2.4.1 *Specifications and Characteristics*

FBA is chemically similar to PFA, and typically comprises ash which has agglomerated in the furnace and ash hopper to form clinker. The size of FBA varies from 50mm to a few centimetres. FBA consists mainly of silica and alumina and its physical characteristics are similar to those of river sand and resemble those of a weak aggregate. FBA is a product of commercial value and is usually sold worldwide for use in the building trade.

(15) EPD Communication, Hoi, Y.K. (EAPG) to Laister, S.L., (ERL) *"EIA for the LTPS at Black Point, Solid By–Product Key Issue Report"* Ref 2/G/39 VIII (18 October 1991).

Figure 2.3a – Annual CLP PFA Arisings – SCENARIO I

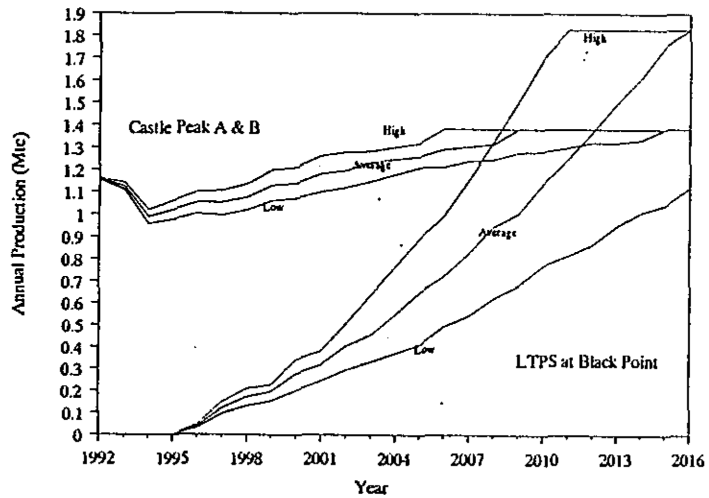


Figure 2.3c – Annual CLP PFA Arisings – SCENARIO II

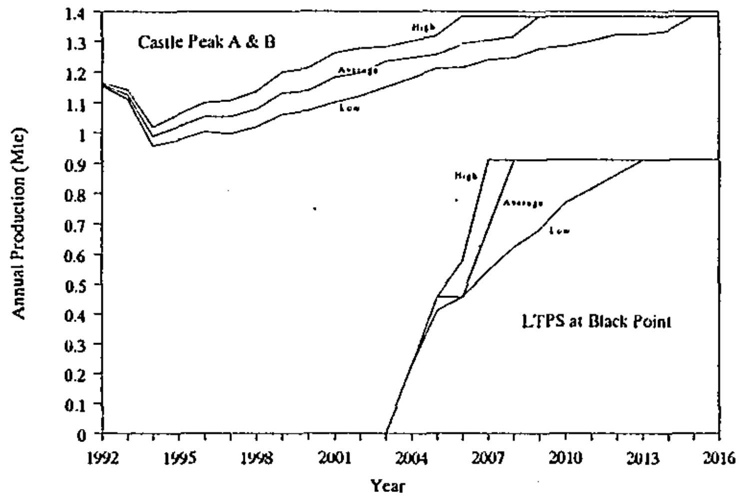


Figure 2.3b – Cumulative CLP PFA Arisings – SCENARIO I

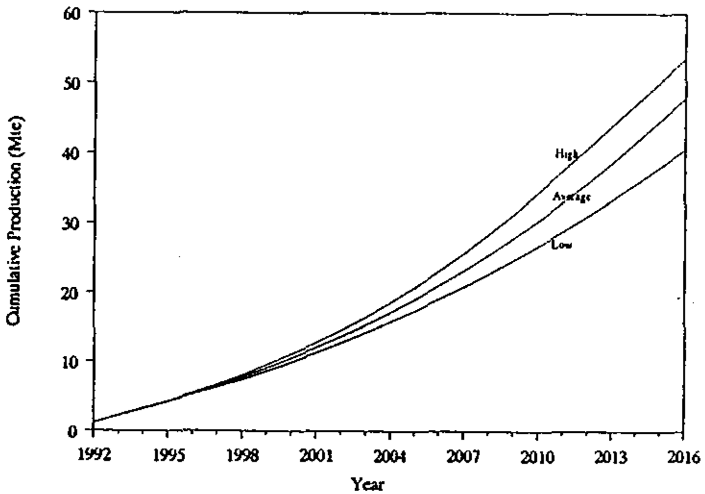


Figure 2.3d – Culmulative CLP PFA Arisings – SCENARIO II

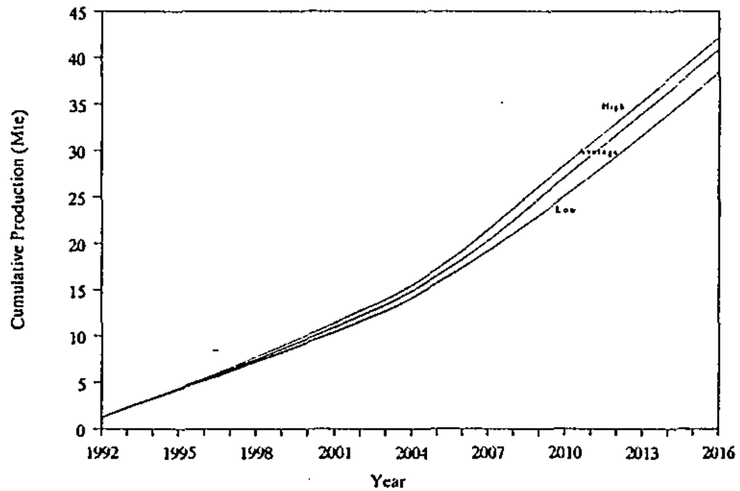


Figure 2.3(a–d)

CLP PFA Arisings

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

Figure 2.3e – Annual HEC PFA Arisings

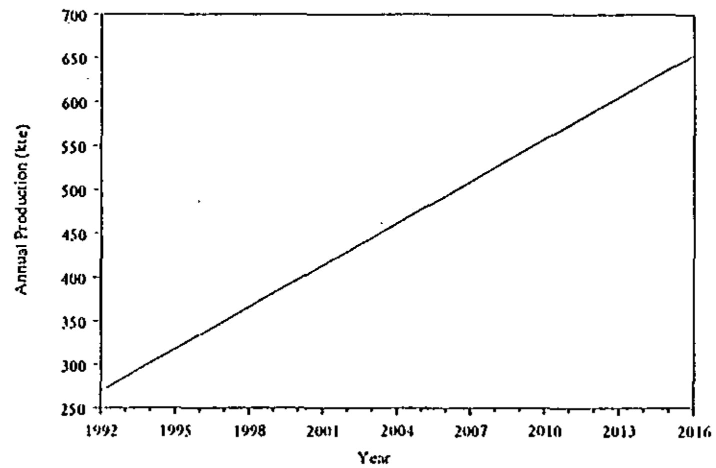


Figure 2.3f – Cumulative HEC PFA Arisings

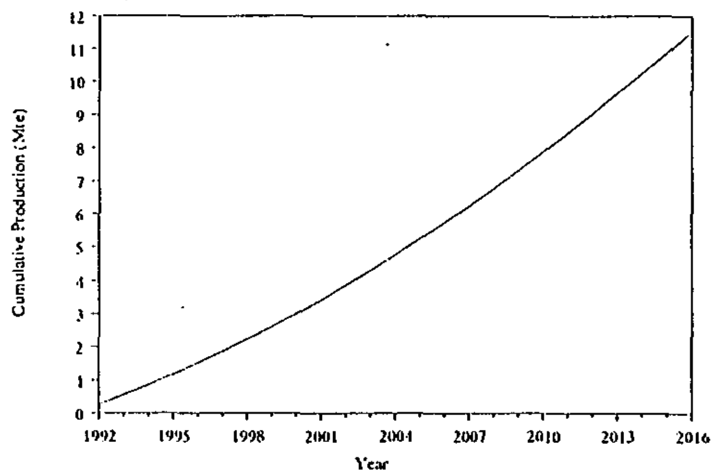


Figure 2.3(e–f)

HEC PFA Arisings

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

2.4.2 *FBA Arisings*

Furnace bottom ash (FBA) arisings are determined based on the coal burn figures given in *Section 2.2* and the assumed average ash content of the coal. It is assumed that 10% of the ash produced will be FBA based on Castle Peak experience.

Hence the FBA produced annually is given by:

$$\frac{te}{yr}(FBA) = \frac{te}{yr}(coal) x 0.16 x 0.1$$

Figures 2.4(a)–(d) show annual and cumulative projections at CLP's TPSs under Scenarios I & II. Detailed figures can be found in *Appendices A and B.*

HEC also produce quantities of FBA as depicted in *Figures 2.4(e)–(f)*. (Data from [15])

Currently all FBA produced in the Territory is utilised, mainly in the manufacture of concrete blocks.

During potential periods of oil firing no FBA would be produced with the overall affect of reducing cumulative arisings by 2016 slightly.

2.5 *FGD GYPSUM*

2.5.1 *Specifications and Characteristics*

FGD gypsum is the major solid by–product from the conventional limestone/gypsum FGD system which can reduce sulphur emissions by in excess of 90% with benefit to the environment as discussed in the Air Quality KIR[16]. The specifications and characteristics depend on the primary process configuration, coal and limestone specification and the degree of secondary processing (washing and thickening). Note, CLP are also investigating the possibility of adapting the conventional design to allow direct dissolution of the gypsum in the cooling system – avoiding any arising of solid by–product all together. This is effectively the middle ground between conventional limestone/gypsum FGD, using limestone reagent and fresh water to give a solid product, and seawater FGD which utilises seawater and lime reagent to give a dissolved product gypsum. The option is discussed more fully in *Section 5.*

(a) *Chemical, Physical and Engineering Properties*

Based on various preliminary designs for conventional limestone/gypsum FGD systems at the LTPS from potential vendors and accounting for the likely worst case limestone composition, the broad specifications for the product gypsum would be within the range given in *Table 2.5(a)*. (Arisings are based on a product of 83.5% dihydrate at 10% absorbed water).

(16) ERL (Asia) Ltd *"EIA of LTPS at Black Point, Air Quality KIR"* for CLP (January 1992).

Table 2.5(a) *Composition of Product Gypsum (wet basis)*	
Component	**High Grade Gypsum** **wt %**
$CaCO_3$	2.5 - 7.0
Inerts	1.0 - 3.0
$CaSO_4$ $2H_2O$	80.0 - 95.0
$CaSO_3$ $½H_2O$	1.0 - 5.0
Absorbed Water	4.0 - 20.0

The range given in *Table 2.5(a)* includes high grade (i.e. high purity with low levels of contaminants) gypsum that at 4.0% moisture would be suitable for commercial applications. At high absorbed water contents the product would be in a suitable form for disposal to landfill.

Relevant physical properties of FGD gypsum from an existing TPS at Voerde in Germany are given in *Table 2.5(b)*[17].

Table 2.5(b) *Physical Properties of Voerde FGD Gypsum*	
Property	**Voerde Gypsum**
Particle size distribution:	
D50 size (mm)	0.034
Uniformity Coefficient	1.7
Moisture Content:	
As received (%)	8 - 10
Optimum for Compaction (%)	15 - 20
Bulk Density at 15% moisture content, BS Standard compaction (kg/m^3)	1400
Permeability, k (m/s)	1×10^{-6}

(b) Trace Constituents

The chemical analysis of any FGD Gypsum CLP produces would obviously be dependent on the quality of the coal, water and limestone used in addition to the particular process configuration adopted:

(17) Ove Arup & Partners *"Flue Gas Desulphurisation Solid Waste Disposal Study, Limestone/Gypsum Process"* for Central Electricity Generating Board (UK) (1988).

Figure 2.4a – Annual CLP FBA Arisings – SCENARIO I

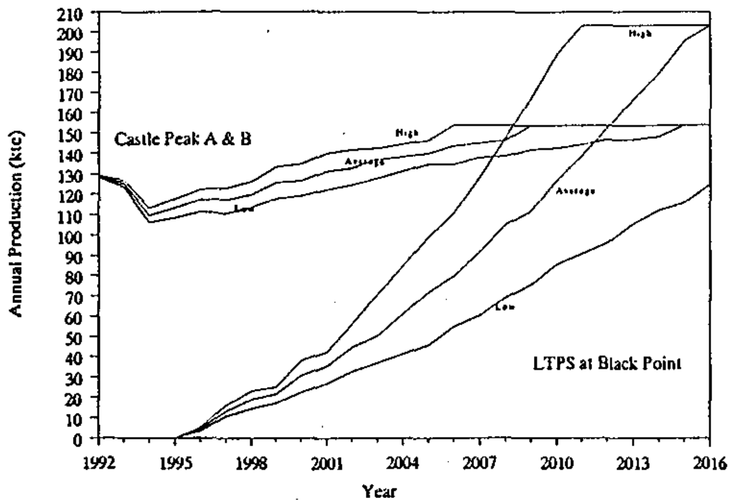


Figure 2.4c – Annual CLP FBA Arisings – SCENARIO II

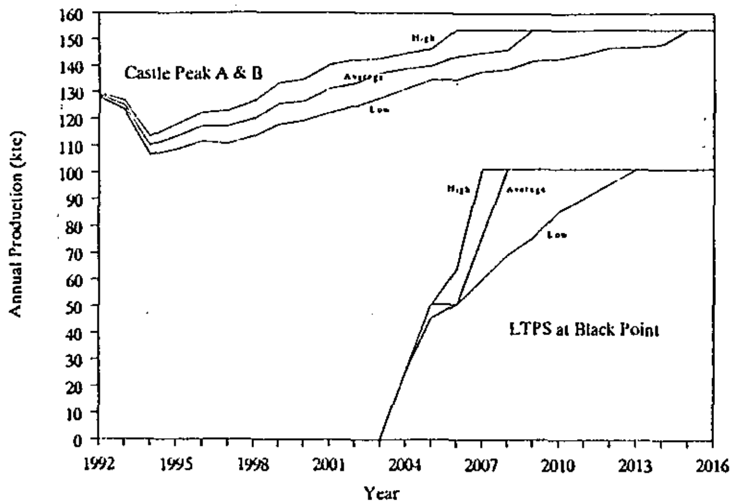


Figure 2.4b – Cumulative CLP FBA Arisings – SCENARIO I

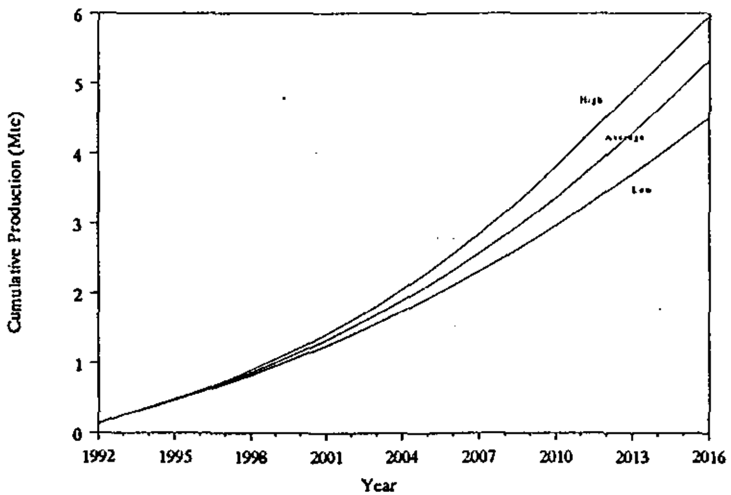


Figure 2.4d – Cumulative CLP FBA Arisings – SCENARIO II

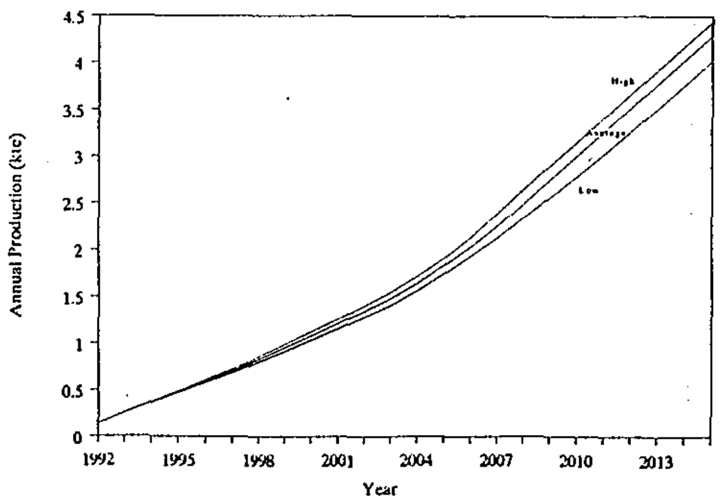


Figure 2.4(a–d)

CLP FBA Arisings

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Figure 2.4e – Annual HEC FBA Arisings

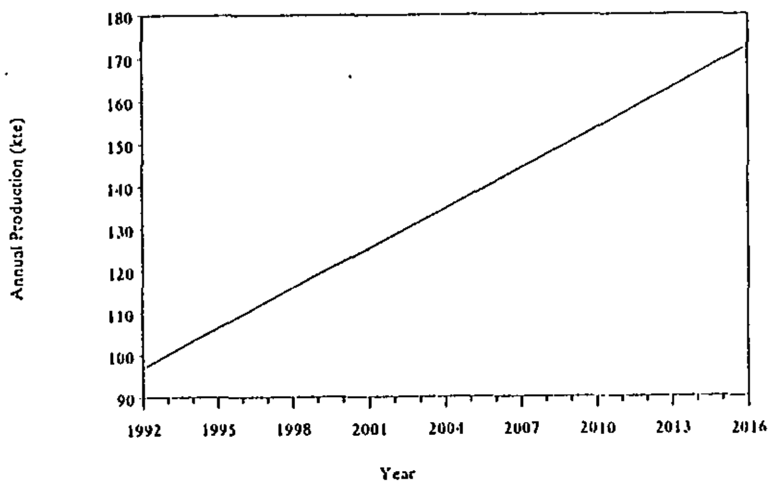


Figure 2.4f – Cumulative HEC FBA Arisings

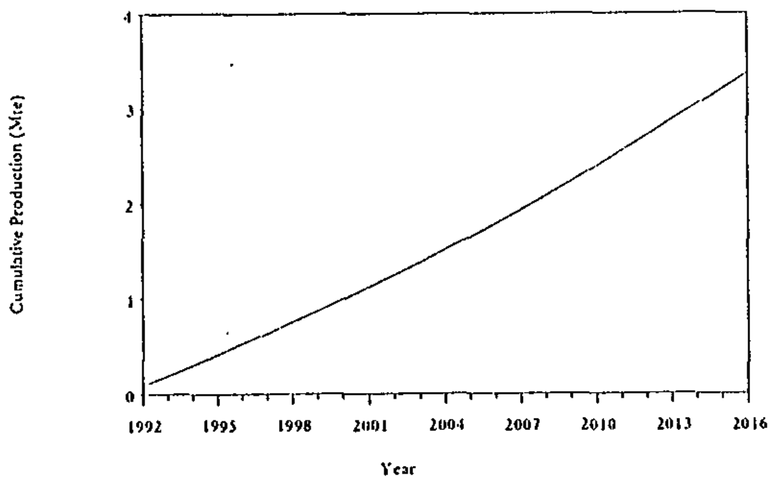


Figure 2.4(e–f)

HEC FBA Arisings

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

- *Coal*

The effects of this condensation process described in *Section 2.3* are particularly important in the case of the smallest particles of fly ash that are not trapped by the electrostatic precipitators and pass to the FGD system. These particles have a much greater specific surface area than the larger particles in the bulk fly ash, and there is therefore a disproportionate degree of condensation of the volatile elements on these smaller particles. Concentrations of volatile trace elements have been reported[(18),(19)] to increase as particle size decreases.

The particular significance of enrichment in the context of the FGD processes is that a major proportion of the elements condensed on particle surfaces are readily leached from the particles by the acidic scrubbing solution. As would be expected, the degree of leaching of these contaminants is a function of the contaminant and the pH of the scrubbing medium.

- *Limestone*

The purity of limestone intended to be used for FGD at the LTPS is in excess of 90%. In addition to the principal contaminants, magnesium oxide and carbonate, limestones contain trace amounts of heavy metals and other elements which will be dissolved during limestone slurry preparation and during operation of the FGD process. In view of the acidic conditions in the absorber, it may in the worst case, be assumed that dissolution of trace contaminants in the limestone will be essentially complete. Trace metals normally occur at ppm levels. Concentrations in a typical limestone source that might be used at the LTPS were shown in *Table 2.2(a)*.

- *Process Water*

Feed water for the FGD system and limestone slurry preparation plant will normally contain trace concentrations of heavy metals and other substances. Evaporation of water (due to the heat content of the flue gases), and thus concentration of these contaminants, takes place during the FGD process. Concentrations of trace metals in a worst case LTPS process water were shown in *Table 2.2(a)*.

No gypsum is produced locally and so no local chemical analyses (and hence leachate analyses) are available. *Table 2.5(c)* shows chemical analyses of three high grade (commercial) gypsums produced at power plants in Germany. A modelled prediction of the likely quality of LTPS FGD gypsum is also shown. The Consultants' model (introduced in the IAR[(3)]) uses the chemical analyses of the feedstocks (*Table 2.2(a)*) and accounts for the pathways of each species through the furnace, ESP and FGD systems to the product gypsum. The model prediction for both Steinkhole TPS and the LTPS are shown for comparison. The Steinkhole results can be compared with the actual analysis[(20)].

(18) Natusch, D.F.S., Davison, R.L. Lamb, R.G., Wallace, R.R. and Evans, C.A. 1973 *"Toxic Metals in Airborne Particles"*, Third International Clean Air Congress Proceedings, Dusseldorf, FRG.

(19) Smith, R.D., Campbell, J.A. and Nelson, K.K., 1979, *Environmental Science and Technology* 13,553.

(20) VGB Technische Vereinigung der GrossKraftwerksbetreiber E.V. *"Messung der Schwermetallabscheidung einer Rauchgasentsch wefelungsanlage nach dem Kalkwaschverfahren."* Kommission der Europaischen Gemeinschaften, Brussel, Marz 1982.

(c) *Leachate Analyses*

Other than physical stability, the main concern of disposing of wastes is their impact on water quality. A report to the Central Electric Generating Board (CEGB)[17] in the UK showed that the composition of leachate from German FGD Gypsum (see *Table 2.5(c)*) at the initial stage of landfilling is high in dissolved solids such as calcium and sulphate. Dissolved solids tend to decrease with prolonged leaching. The composition of leachate from two FGD gypsums are given in *Table 2.5(d)*.

2.5.2 *FGD Gypsum Arisings*

Arisings for high grade FGD gypsum have been calculated based on the consumption of limestone and the product compositions given above. The production rate per tonne of coal fired used to calculate the data presented in the tables in *Appendices A & B* is 55.8 kg/te (coal).

Note that if the boiler units were to be fired with 3.5% sulphur heavy fuel oil then the quantity of gypsum produced during oil burning periods would increase by roughly a factor of 2 to about 110 kg/tonne of coal equivalent (based on the emission rates of SO_2 assuming 90% removal as given in [16].

Figure 2.5(a)–(d) show the annual and cumulative FGD gypsum arisings under *Scenario I & II* firing respectively.

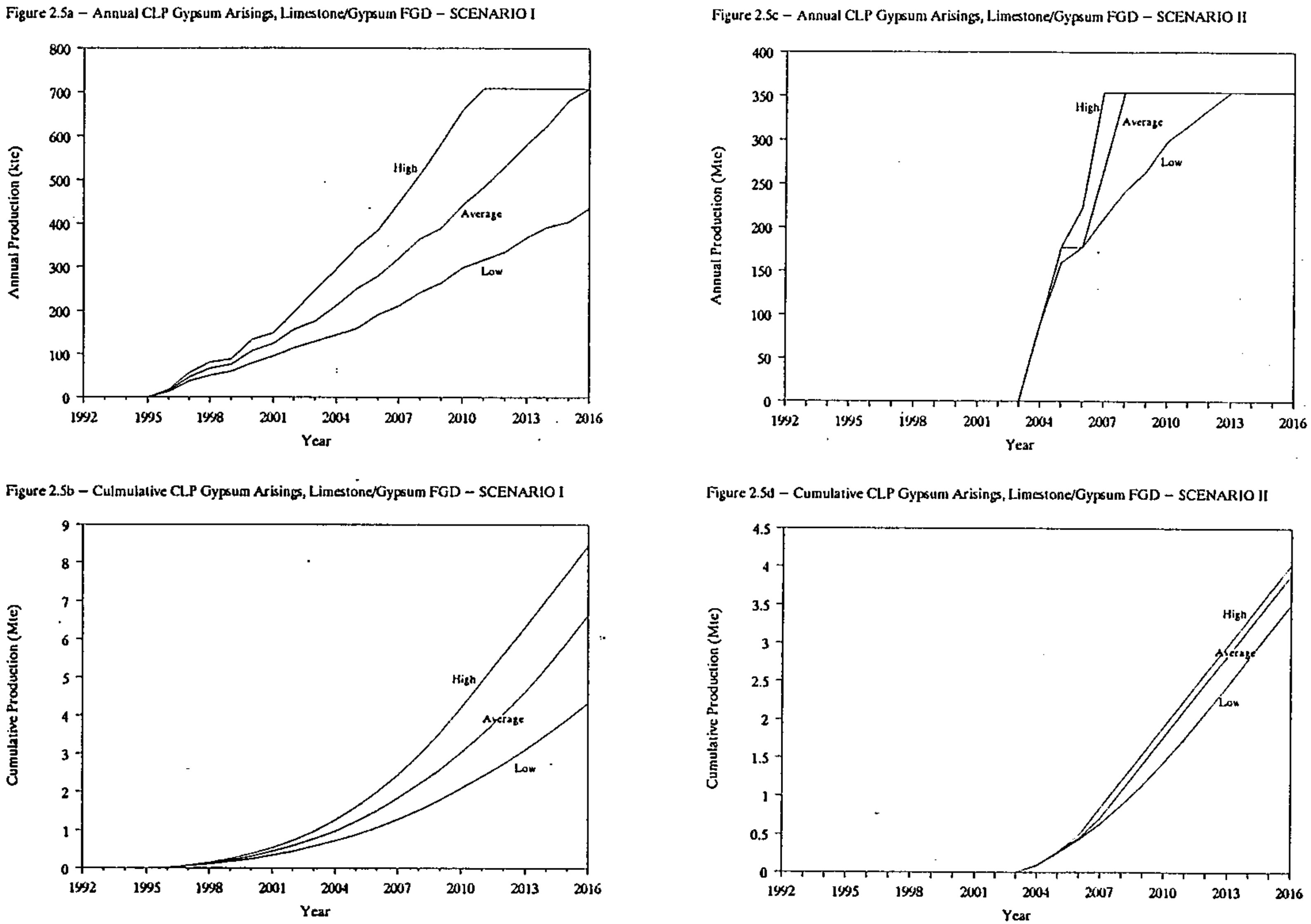


Figure 2.5(a–d)

CLP Gypsum Arisings, Limestone/Gypsum FGD

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Table 2.5(c)
Chemical Analyses of FGD Gypsum

	Riedersbach FGD Gypsum	Voerde FGD Gypsum	Steinkhole FGD Gypsum		Modelled LTPS FGD Gypsum
			Modelled	Actual	
Moisture loss @20°C (%)	5.4%	8.4%	–	–	–
pH	7.1	6.7	–	–	–
Electrical Conductivity (µs/cm)	1650	1750	–	–	–
Total Alkalinity ($CaCO_3$)	26500	4,500	–	–	–
Calcium (Ca)	20.7%	20.1%	–	–	–
Magnesium (Mg)	113	46	–	–	–
Sodium (Na)	2340	1760	–	–	–
Chloride (Cl)	20	40	–	–	–
Floride (F)	140	90	–	–	–
Sulphite (SO_3)	<50	<50	–	–	–
Sulphate (SO_4)	51.7%	50.5%	–	–	–
Silicon (Si)	375	470	–	–	–
Iron (Fe)	340	250	–	–	–
Aluminium (Al)	100	200	–	–	–
Boron (B)	<10	<10	–	–	–
Arsenic (As)	<1	2.1	0.53	0.50	0.67
Cadmium (Cd)	–	–	0.17	0.062	0.83
Chromium (Cr)	–	–	0.70	0.71	3.35
Copper (Cu)	17	<10	1.13	0.80	1.50
Mercury (Hg)	0.08	0.08	0.16	0.09	0.25
Molyedenum (Mo)	23	65	–	–	–
Nickel (Ni)	27	12	0.73	0.41	3.88
Lead (Pb)	–	–	6.26	5.76	1.47
Zinc (Zn)	–	–	17.60	13.30	5.79
Selenium (Se)	2.6	<1	–	–	0.43
Antimony (Sb)	–	–	0.17	–	–
Total Inorganic Phosphate (PO_4)	<200	<200	–	–	–
Nitrate (NO_3 – N)	13	16	–	–	–

Notes : All results expressed as mg/kg dry basis except where specified.
– Data not available LTPS modelled figures for indicative purposes only – will vary with feedstock composition.

Table 2.5(d)
Leachate Analyses FGD Gypsum

	Leachate of Riedersbach FGD Gypsum	**Leachate of Voerde FGD Gypsum**
pH	6.45	4.60
Electrical Conductivity (μs/cm)	2,400.00	2,200.00
Total Dissolved Solids (TDS)	1460	2500
Total Alkalinity ($CaCO_3$)	890.00	105.00
Calcium (Ca)	950.00	610.00
Magnesium (Mg)	2.80	2.30
Sodium (Na)	7.00	2.30
Chloride (Cl)	0.15	1.70
Floride (F)	4.00	5.00
Sulphite (SO_3)	<5.00	<5.00
Sulphate (SO_4)	1,210.00	1,430.00
Silicon (Si)	0.40	6.20
Iron (Fe)	<0.03	<0.03
Aluminium (Al)	0.20	6.90
Boron (B)	<0.03	<0.03
Arsenic (As)	<0.01	0.01
Copper (Cu)	<0.03	<0.03
Mercury (Hg)	0.001	0.008
Molyedenum (Mo)	0.26	0.10
Lead (Pb)	0.05	0.03
Selenium (Se)	–	–
Total Inorganic Phosphate (PO_4)	<0.03	0.04
Nitrate (NO_2 – N)	<0.10	0.10
Chemical Oxygen Demand (COD)	1100	470

Note : All results expressed as mg/l except pH except where specified.

2.6 FGD WASTEWATER TREATMENT SLUDGES

2.6.1 Specifications and Characteristics

Analysis of wastewater treatment sludge at the FGD plant at Voerde Power Station showed that the FGD sludge was a non-plastic material with a grading distribution wider than that of gypsum, covering the full range of silt and sand sized particles[17]. When dewatered to 25% moisture content, it acts as a dry cake suitable for transport to disposal sites. However, in this state it is not suitable for use as load bearing fill.

The composition of sludge produced will be dependent on the PFA collection efficiency of the ESP, specification of coal and limestone, extent of oxidation and the FGD wastewater treatment processes. Typically, it will consist of approximately 10 - 35% (w/w) PFA, 55 - 70 (w/w) calcium sulphate and the remainder will be insoluble metal hydroxides (principly Mg, Fe, Al), oxides (Si), sulphides and other impurities from the limestone reagent used.

Table 2.6(a) shows the composition of the FGD Wastewater Treatment Sludge and its leachate.

2.6.2 Wastewater Treatment Sludge Arisings

Arisings of wastewater treatment sludge (if wastewater treatment is to be incorporated into the design) will depend to a large degree on the extent of treatment in addition to the compositions of the limestone reagent and process water to be used. This information is not available at present and figures presented in the appendices are taken from the DIAR based on 5.1 kg (sludge)/te (coal) and represent a very conservative (pessimistic) estimate. More optimistic estimates could halve the total sludge arisings (for example Steinkhole TPS in Germany produces only about 2.4 kg/te (coal), but incorporates very high efficiency ESPs and relatively pure reagents). *Figures 2.6(a)-(d)* show annual and cumulative arisings for Scenarios I & II.

Table 2.6(a)
Chemical Analyses of Waste Water Treatment Sludge (WTS)

	Steinkohle WTS	Voerde Water Treatment Sludge	Voerde Leachate
pH	–	8.3	5.4
Electrical Conductivity (μs/cm)	–	1900	4800
Total Dissolved Solids	–	–	7450
Total Alkalinity ($CaCO_3$)	–	99500	2100
Calcium (Ca)	–	19%	1000
Magnesium (Mg)	–	9500	500
Sodium (Na)	–	2590	25
Chloride (Cl)	–	2300	156
Floride (F)	–	540	20
Sulphite (SO_3)	–	<50	<5
Sulphate (SO_4)	–	46.5%	1790
Silicon (Si)	–	13100	6.3
Iron (Fe)	–	9700	0.03
Aluminium (Al)	–	8400	65
Boron (B)	–	140	6.3
Arsenic (As)	3.0	4.8	0.08
Cadmium (Cd)	3.3	–	–
Chromium (Cr)	12.6	–	–
Copper (Cu)	20.5	32	0.02
Mercury (Hg)	6.1	1.7	0.001
Molyedenum (Mo)	–	32	<0.1
Nickel (Ni)	18.0	–	<0.03
Lead (Pb)	68.0	100	–
Zinc (Zn)	256.0	–	–
Selenium (Se)	116.0	–	<0.03
Antimony (Sb)	<0.1	–	–
Total Inorganic Phosphate (PO_4)	–	210	<0.03
Nitrate (NO_2 – N)	–	49	2.2
Chemical Oxygen Demand (COD)	–	–	4300

Notes : All results expressed as mg/kg dry basis except where specified.

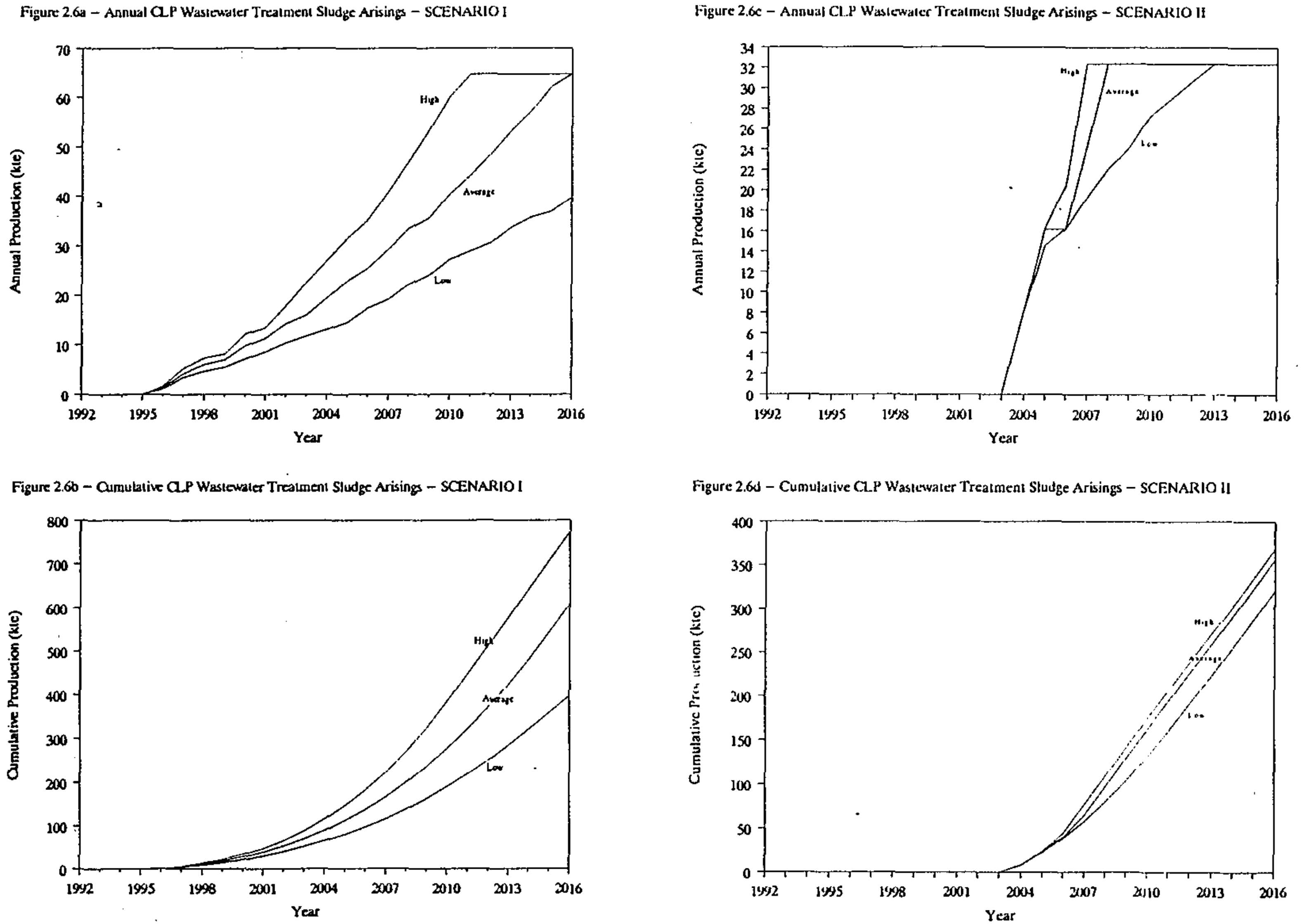


Figure 2.6(a–d)

CLP Wastewater Treatment Sludge Arisings

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

3 PULVERISED FUEL ASH (PFA) MANAGEMENT

3.1 INTRODUCTION

PFA is a by-product of coal combustion and has a number of beneficial uses. Under the high demand forecast and *Scenario I* (all coal firing) CLP would be producing a total of about 3.2 Mte/yr in 2016; a cumulative quantity of up to 54 Mte (there are in addition, currently about 2 Mte in Tsang Tsui ash lagoons). HEC could be producing upto 0.65 Mte/yr; a cumulative total of 12 Mte[15] by 2016. Other industrial concerns could also be producing PFA or similar residues, although in much less significant quantities.

Previous studies (see below) have identified several markets for PFA. Disposal options for material that cannot be beneficially utilised are well known, but suitable sites are scarce.

Currently CLP utilisation stands at about 0.3 - 0.4 Mte/yr out of a production of 0.9 Mte/yr and the expectation is that a similar annual utilisation can be maintained given no change in the current regulatory and general market conditions.

There is reason to believe however that significantly more PFA could be utilised in Hong Kong given the appropriate management, marketing and regulatory framework. Experience elsewhere in the world demonstrates what is possible. Holland is believed to use *all* its power station PFA beneficially. France, Germany, Britain, Japan, China, the former USSR, Canada, Australia, Eastern Europe and the USA all utilise significant proportions of their PFA arisings, the principle use being in cement and concrete. Codes of practice and regulations often encourage, or even mandate this usage, particularly in countries where landfill space is restricted through availability (as in Hong Kong) or where environmental concerns over waste disposal are a prominent political issue.

PFA utilisation in Hong Kong may follow this worldwide trend, however CLP need to be prepared for the worst case of little or no increases in utilisation. Hence, backup disposal facilities are required for the arisings. This study has considered the first 20 years of LTPS operation up to 2016.

In Hong Kong the issues of PFA (and FBA) disposal/utilisation were covered in the Waste Disposal Plan for Hong Kong[21] which concluded:

> *"the preferred option for disposal of PFA and FBA is sale on a commercial basis, followed by lagooning if sale outlets cannot be found. Use of PFA and FBA in land restoration and reclamation is to be investigated as a possible long-term solution to the disposal problem."*

The Consultants have endeavoured to follow this heirarchy where possible.

(21) EPD, Waste Disposal Authority *"Waste Disposal Plan for Hong Kong"* Planning, Environment and Lands Branch, Government Secretariat (1989).

3.2 *BENEFICIAL UTILISATION OF PFA*

3.2.1 *The Options*

Options for the beneficial utilisation of PFA have been discussed in numerous studies worldwide and, specifically in Hong Kong[(3),(7),(22),(23)]. Some summaries of CLP's own investigations are included as *Annex C*. The IAR identified and briefly discussed options then seen as potential markets:

- Cement manufacture;
- Concrete additive;
- Reclamation above and below the waterline;
- Export;
- Structural and bulk fill;
- Site restoration;
- Miscellaneous uses including applications in artifical reefs, reinforced earth walls, chunam, mortar and render, grouts, filler in asphalt, water treatment and chemical waste management.

Of the above, some have been discounted as having no or severely limited (to the extent that negligible effect on arisings would be noticeable) potential in Hong Kong so far as can be foreseen at present and hence have not been investigated in detail here. Export, whilst of significance at present, is seen as having little long-term security due to China's growing production of PFA and its greater proximity to local users. To the above uses the KIR has added:

- Interleaving material at municipal landfills;
- Lining and capping material for municipal landfills in the form of a PFA/bentonite mix;
- Manufacture of autoclaved aerated concrete blocks;
- Soil ameliorant/N-Viro Process;
- Lightweight Aggregates.

CLP's power plants operate to satisfy a baseload electricity demand that rises from a steady winter demand to a peak during the hottest summer months. Strategies for the utilisation of PFA (which is produced in direct proportion to electrical output from coal-fired units) that have a significant continuous demand are therefore preferred. Those options with large intermittent demand, such as fill, were also considered in the KIR, but are not as desirable, since PFA product would first have to be stockpiled in quantity at lagoons or other sites. However, such uses would serve to reduce the requirements for disposal capacity.

(22) Binnie Consultants Limited, *The Environmental Aspects of Fuel Ash Utilisation,* for CLP (1991).

(23) Ash Marketing, CLP, *Ash User's Guide,* (1990).

3.2.2 *PFA as a Constituent in Cement Clinker*

PFA is used extensively worldwide as a raw material in the manufacture of cement clinker wherein it is used as a component of the raw mix and replaces other feedstock materials. After firing, the cement clinker is chemically and physically indistinguishable from cement clinker produced without PFA.

(a) Economic and Technical Benefits

The production of cement clinker within Hong Kong reduces the need to import the product. After allowing for raw material costs it has been estimated that savings on Hong Kong's balance of trade amount to around HK$120 million per annum if China Cement Company's (CCC's) kiln operates at capacity. These savings are very substantial and underline the value of the local cement production industry. CLP's existing Castle Peak Power Stations and the proposed LTPS are both conveniently located close to the only cement kiln in Hong Kong which produces about one third of the Territories cement. The fly ash produced by the power station is largely composed of silica, alumina, lime, carbon, magnesia and iron and each of these elements is necessary to the production of cement clinker. The PFA used replaces up to approximately 20% of the raw mix, all of which would have been imported into Hong Kong.

In the present market it is more economic to produce cement clinker in Hong Kong than import it. However it is unlikely that clinker production capacity will be increased in the near future. CCC cite high capital costs of process and pollution control technology and land availability as constraints on increasing capacity.

(b) Environmental Aspects

The environmental benefits of utilisation in cement are threefold:

- Elimination of a significant quantity of a material requiring large and intrusive disposal facilities.
- Energy savings. The manufacture of cement clinker is an energy intensive process. Firstly a considerable amount of energy is required to grind raw materials to a fine powder. PFA already has a small particle size distribution and hence does not require the same degree of grinding. Subsequently the raw materials must be fired at very high temperatures – requiring further energy. Much of this energy is required to calcine the lime component. Replacement with PFA means some of the lime content is precalcined and the carbon content of the ash supplements the fuel, hence less energy is required using PFA than with raw limestone.
- Elimination of the need to quarry/produce alternative materials that would otherwise be incorporated into the cement. Thus there would be some secondary environmental benefits in the form of reduced emissions and energy consumption at the production locations and in the transport operations.

(c) *Market Potential*

China Cement currently consumes approximately 160,000 tonnes per annum of PFA in the manufacture of cement clinker. This is about 18% of the PFA currently produced by CLP. An increase in this figure would only be possible by the addition of a further kiln and precalciner. As mentioned above it is most unlikely that it would be economic to build a second full size kiln at China Cement. To do so would require the China Cement site to be extended by some 5-10 ha and an investment made of around HK$1 billion.

CLP are however concerned that production of clinker could cease due to economic and/or environmental pressures on CCC and they believe that due consideration needs to be taken by the authorities when assessing the problems peculiar to the cement industry.

On the assumption that the kiln remains in operation, utilisation of ash for clinker production should remain at its present level.

(d) *Strategy and Recommendations*

It is considered that the economic and environmental benefits of the use of PFA as a constituent of cement clinker is the best use for the material locally. As such every effort should be made by CLP and government authorities to ensure that clinker production is encouraged in the future.

3.2.3 *PFA as a Partial Cement Replacement in Concrete*

PFA is used widely around the world as a partial replacement for cement in concrete. Used in proportions of up to 50% of the total cementitious content (TCC) - i.e. the cement plus PFA, but not the aggregate. Such concretes find their way into all manner of structures.

The partial replacement of cement by PFA in concretes is usually accomplished in two ways:

- By the use of blended cements produced in the works by intergrinding cement clinker with PFA or by blending ground cement with controlled amounts of quality controlled PFA (This is PFA which has been ground or classified). Such cement/PFA blends are known as Portland Pulverised Fuel Ash Cements (PPFAC) and are governed by internationally recognised standards including BS6588 and BS6610.

- By the addition of quality controlled PFA in the concrete mixing (or "batching") process to which BS 3982: Part 1: 1982 is applicable.

Worldwide utilisation is large, for example in parts of Australia, for every 100 te of cementitious material used in concrete an average of 14 te are PFA, compared to 6 te in the USA and 7 te in the UK and about 2 te currently in Hong Kong[24]. Use is often only limited by the availability of PFA or by costs of transportation. The most common proportion of PFA is 25% of the total cementitious content (TCC). PFA use in concrete is mandatory in countries such as France and Holland.

In Hong Kong, PFA has only recently been allowed to be incorporated in structural concrete in non-Governmental structures. It has been incorporated however into numerous Government projects usually at the rate of 25% replacement of TCC.

Some of the projects which have used PFA are the Harbour Road Government Office Buildings, Tsim Sha Tsui Cultural Centre, Pak Kong Water Treatment Works, Route 5 Expressway, Eastern Harbour Crossing, MTR tunnel walls, the parking aprons at Kai Tak CLP's new power station at Penny's Bay and its lagoons at Tsang Tsui, Tsing Yi North Bridge, Kwai Chung Road Flyover and Asia's new tallest building; Central Plaza[7],[22],[23],[24],[25].

The current regulatory position is as follows:

- *Private Sector:* The Buildings Ordinance Office (BOO) state in their Practice Note[26] that PFA content should not exceed 25% of TCC however scope exists to use higher levels with special controls and a detailed submission to BOO.

- *Government Sector (except Housing):* The Lands and Works Branch Practice Note Addendum[27] maintains that in certain instances the use of in excess of 25% of TCC (up to 40%) may be beneficial, such as in mass concrete or in very large sections. The builders of Central Plaza cite this reason for using PFA.[26] However, the Standing Committee on Concrete Technology must be consulted for approval of intended replacements in excess of 25%.

  - The use of PFA, if available, is now specified by Highways Department in road paving quality concrete in Hong Kong at a mandatory 25% of TCC.

- *Government Housing:* In the past Housing Department have precluded the use of PFA concrete in their projects and have no practice note covering the issue.

(24) L.G. Mouchel & Partners Ltd. and Taywood Engineering Ltd., *PFA Concrete Studies, Volumes 1 - 8*, for CLP (1990).

(25) Lam, C.F., *"Central Plaza - 78 Storage Intelligent Building, EPD Site Visit"* Hong Kong Engineer, (September 1991).

(26) Buildings Ordinance Office, *The Use of Pulverised Fuel Ash in Concrete,* Practice Note for Authorized Persons and Registered Structural Engineers, Ref. BLD(B) GP/BREG/C/7 (February 1992)

(27) Works Branch, *Use of PFA in Structural Concrete*, Addendum No.1 to LWB PN 4 (September 1990).

Some Departments have not generally accepted PFA in their concrete. However, the situation is changing. For example, Housing Department intend to use PFA in the foundations of four major projects this year[28]. Housing Department were formely not a PFA user, but this has altered over the course of this study. Authorities such as the BOO have until recently imposed conditions upon the use of PFA concretes which have been sufficiently onerous to render the use of the material unattractive to building contractors notwithstanding the cheaper price. This situation is also changing to one of advocation of PFAs use as specified in this years revised Practice Note[26].

(a) *Economic and Technical Aspects*

The following is an extract from the Lands and Works Branch Practice Note No.4, Addendum No.1 entitled 'The Use of PFA in Structural Concrete'[27]:

> *"... Replacing cement with PFA therefore reduces the need to import cement, clinker or raw materials and reduces the amount of energy used in local processing and thus the production of PFA itself. During 1989, Hong Kong used about 4M tonnes of cement, and produced about 1M tonnes of PFA. If 25% of all cement used in Hong Kong were replaced with PFA, there would be a saving in the cost of imported materials alone of $300M p.a., and the problem of disposal of ash as a waste material would cease to exist. ... There is a general shortage of cement in the region at present (as witnessed by CCC's recent re-firing of its kiln) and it is forecast to worsen. The price of cement is climbing faster than that of most other construction materials".*

The technical benefits of using PFA as a partial replacement in concrete are well known from previous studies[24]. The Works Branch Practice Note summarises these as follows:

"- *improved long term performance in terms of strength;*
- *improved durability through reduction in mixing water;*
- *improved cohesion and workability for a given water content;*
- *improved surface finish;*
- *improved resistance to sulphate attack;*
- *reduced heat of hydration;*
- *reduced shrinkage and cracking;*
- *reduced bleeding;*
- *resistance to alkali-silica reaction."*

Disadvantages are its sensitivity to water content and initial curing. These can be overcome with extra care in concrete batching operations and quality control measures. Early concerns over colour have been discounted according to the Practice Note.

In order to ensure the quality of the PFA to be used and hence the quality of the concrete produced, PFA must be processed to meet B.S. 3892 standards which govern properties such as particle size and unburnt carbon content. This can be achieved by grinding or classification and such processes are currently carried out by three operators in Hong Kong namely China Cement, Kin Ching Besser and Lamsonite. CCC are the only company with the ability to intergrind PFA with cement clinker. CLP is currently installing a classification plant at Castle Peak TPS in order to ensure the supply of compliance grade PFA to all potential customers. The proposed plant will screen off the larger particles and reduce the carbon content of the PFA.

(28) South China Morning Post, *Engineers Find Use For Waste*, (Thursday, March 26, 1992).

The Lands and Works Branch Addendum states that economic benefits from the use of PFA as a partial cement replacement in concrete should not necessarily be expected, but indicates that costs should not increase. The Consultants see no reason why overall costs should not decrease once operators are aware of technical requirements, as indicated recently by a Government offical[28].

(b) *Environmental Aspects*

Environmental benefits and concerns are much the same as those described in *Section 3.2.2(b)* above in respect of energy saving and reduction in quarrying activity except that potential savings in disposal facility capacity would be greater (see below). Conversely the potential for adverse environmental impact due to fugitive and transport-related dust emissions would be present, but is unlikely to be more significant than existing cement handling operations. A recent report[22] concluded that:

> *"... where appropriate control and management procedures are employed, the use and disposal of PFA in the construction industry is unlikely to present any significant environmental difficulties."*

The Consultants agree with this statement. PFA would be supplied classified or blended as PPFAC. Mitigation of fugitive dust emissions would be aided by the adoption of tight quality control measures, such as those required for accreditation under ISO 9000. Such a measure would also help to ensure the quality of batched concrete.

Use of PFA as a cement replacement has some secondary benefits to the environment in that it saves energy that would otherwise have been used to manufacture the cement clinker and to initially quarry the raw materials. Associated with the above would be reductions in emissions of pollutants from energy and cement production

Concerns have been expressed in the past over radiation and emissions of radioactive radon gas from concretes made with PFA. The origin of these concerns centres on the concentration that occurs during coal combustion of small particles of naturally occuring radionuclicides in the ash. These particles are present in the raw coal and remain in the ash residue, thereby increasing the radioactivity of the ash compared with the raw coal product. However, the effect of radioactivity is not just due to the concentration of radioactive material in the naturally occurring materials, but to a number of issues. They are:

- The overall concentration of radioactivity in the material.
- The partitioning of that radioactivity between discrete mineral phases, or dissemination throughout that material.
- The primary and secondary permeability of the material.
- The crystalinity of the mineral phases in which the radioactivity is present.

The inter-relationships between these four points are not always as obvious as they at first appear. For example in the UK, the uranium and thorium content of granites in Aberdeen, Scotland are higher than those of the south-west England granites, but the radon risk is much lower because the secondary permeability of the Scottish granite is much less than that of the south-west England granites. It is therefore much harder for leaching groundwaters to release radon from the rock matrix of the Scottish granites.

The radioactivity in sedimentary materials, whilst generally lower, is more likely to be released to the environment than that found in primary igneous rocks such as granite, because of the reworking of the material to form sediments. The weathering and degradation processes which acted on the primary radioactive mineral assemblage has two effects: breakdown of the dense crystalline structure of primary minerals such as monazite and zircon which act as hosts to the radioactivity, and production of secondary, less well ordered, radioactive minerals, which are more easily leachable.

Reworking granites into building materials increases the likelihood of radon release. The increased levels of radioactivity in PFA are comparable with the natural levels of radioactivity to be found in the granites, and so the use of PFA in concrete in combination with granite aggregate will not significantly affect the radiation risk.

A recent report[22] investigated the use of PFA in building materials. The conclusions of this report are consistent with the Consultants observations:

- "*Building bricks in Hong Kong which incorporate granite as aggregate have relatively high levels of radioactivity and local research has shown that incorporation of PFA in addition to the granite aggregate does not alter their radioactivity significantly;*
- *Experience overseas suggests that inclusion of PFA in concrete often reduces the effect of radioactivity by modifying the pore structure in the material and thereby reducing the emission rate for radioactive radon gas....*
- *The radioactivity of coal ash from power stations operated by CLP is not significantly different from that of ashes used in other countries for fill and building materials manufacture."*

Other findings of the study (which has been reviewed by the Consultants as part of the KIR) were that the use of PFA in concrete is of minor radiological significance and that the levels of radiation from the PFA concerned are similar to or less than those deriving from the granite rock that is prevalent throughout Hong Kong and used as aggregate in concrete.

Accumulation of radon gas may occur within buildings where free air circulation is absent, or where recycling/air conditioning processes are employed which do not introduce large quantities of atmospheric air into the building. Whilst these risks have not been quantified, the risks of using PFA are no greater than those of using granite aggregate.

(c) *Market Potential*

Currently about 6 Mm^3 of concrete are used each year in Hong Kong and this figure is set to increase as a result of the commencement of several large infrastructural projects under PADS which will continue up to 2011. Based on current demand, use of PFA at 25% of TCC in all concrete (mean figure) would utilise of a total PFA quantity (concrete and cement) of 600,000 te/yr or about 80% of CPPS production. This maximum figure would be expected to rise in line with growth (or decline) of the construction industry.

Current utilisation of CLP PFA in concrete stands at about 80,000 te/yr. CLP's Ash Marketing Division expect to maintain this figure given no appreciable changes to current demand patterns or the regulatory framework. Positive changes in the regulatory framework now ocurring and in developer practice will however enable substantial increases in consumption (see below).

CLP are themselves using PFA in construction projects, notably in the concrete for new power plants at Penny's Bay and Daya Bay in the PRC. Considerable potential exists for the use of CPPS, and later LTPS, classified PFA in the phased construction of the LTPS, particularly for coal fired units. It has been estimated that a total of 57,600 te of PFA would be required if all eight units were to be coal fired (*Scenario I*) assuming a TCC of PFA of 25%. Concrete pour rates during construction would easily match PFA production at CPPS. For CCGT generating units the concrete requirement is significantly reduced. Based on four CCGTs and four coal fired units (*Scenario II*) about 35,000 te of PFA could be utilised.

(d) *Strategy and Recommendations*

PFA usage in concrete is gradually becoming established as an accepted practice in Hong Kong. Technical, economic and environmental benefits should result from the active encouragement of the use of PFA in concrete production. Any PFA utilised in this manner should conform with the requirements of BS 6588: 1985 for blended cement and BS 3892: Part 1: 1982 if used as a separate constituent.

CLP's planned installation of an ash classification plant should aid the development of a greater demand for PFA as a partial replacement for cement in concrete. There is a low potential for adverse environmental impact for such utilisation, particularly if receiving concrete batching plants conform to quality control procedures set out in ISO 9000.

In certain parts of the world the use of PFA in concrete is mandatory and there appears to be no technical reason why this should not be so in Hong Kong. At a level of, say, 15% no significant alterations to concrete properties would be noticed. CLP would advocate this level as mandatory. Such a practice could cause complications with the importers of bagged cement, but, CLP estimate, would guarantee a market for approximately 600,000 te/year of PFA (averaged over 20 yrs of LTPS lifetime). PFA sold to smaller consumers would all preferably be preblended with cement.

The following steps are necessary to achieve the above utilisation:

- The Housing Department permitting and advocating the use of PFA in structural concrete as appears to now be the trend[28].
- The BOO continuing to review restrictions and conditions imposed upon contractors using PFA concretes in structural applications and actively promoting PFA's use.
- CLP advocate that consideration should be given to the adoption of a 56 day criterion on concrete strength rather than the existing 28 day strength measure.

Further substantial increases could be achieved by considering the use of 25% PFA replacement in concrete to be mandatory at a later date when sufficient supply is available. CLP estimate these actions could increase demand by a further 500,000 te/yr (averaged) producing a net saving to the Hong Kong trade balance of about HK$250 million/year. The cost of implementation (being mainly related to quality control) would probably be insignificant in respect of the latter figure.

3.2.4 *Lightweight Aggregates*

The previous sections (*3.2.2* and *3.2.3*) have discussed the not inconsiderable prospects for increased utilisation of PFA in the construction industry as a constitutent in the manufacture of cement clinker and as a partial cement replacement in concrete. There is a further area where PFA can be used to replace conventional materials in concrete to beneficial effect in terms of technical, economic and environmental issues. This is in the form of synthetic lightweight aggregate, a material that also has applications as a structural or bulk fill.

Concrete is made up of a cementitious content (as discussed in previous sections) and an aggregate content. The construction industry in Hong Kong typically uses crushed granite and fine sands as aggregate in both structural and non–structural concretes. There are however a number of commercial processes for manufacturing gravels and aggregates from PFA. Such aggregates can be used either directly in the ready–mix concrete business, in the manufacture of prefabricated concrete elements; such as floor slabs, building blocks, concrete piles and shore protection blocks for sea defences, or as a coarse aggregate in non–bonded sub–bases and in bitumen–bonded asphalt layers for road construction and structural and bulk fill operations.

Lightweight aggregates manufactured with PFA are in use around the world in both structural and non–structural applications in the USA, Europe (particularly Britain and Holland) and in Japan. For example, London's Nat West Tower used lightweight PFA aggregate to good effect in its construction.

Current legislation and regulations in Hong Kong prohibit the use of lightweight aggregates in structural concrete. Works Branch and BOO would need to approve any proposed uses in the public and private sectors respectively.

(a) *Technical Benefits*

Synthetic lightweight aggregates can be manufactured in two principle forms, both however encompass the same basic operations; PFA and the binder, usually lime, are mixed, pelletised, and then hardened.

The pellets can be made to any size distribution, to suit the end use and can be hardened by:

- Steam curing at low temperatures to produce a hardened aggregate (e.g. "Aardelite" gravels[29] with low energy requirements (the binding reaction with PFA and lime is exothermic providing a portion of the energy required) suitable for most applications.

(29) Aardelite Holding B.V. *"Aardelite – Turning a Residue into a Resource"* The Netherlands.

- Sintering by a hot process at 1200°C to produce stronger aggregates suitable for applications in high strength structural concretes (e.g. "Lytag" light-weight aggregates[30]).

Note that aggregate is not part of the cementitious content and that it does not affect the use of PPFAC cement or PFA as a partial cement replacement in concrete.

The principle technical benefit, is in reducing the main problem with conventional concrete – its weight. Lytag can be used in concretes with a strength range of up to 60 N/mm^2 with an effective reduction in dead load of 25% over normal weight concrete. Hence for structural applications, if less weight is to be supported by the foundations because lightweight aggregate has been used, then the foundations do not require to be so strong and supporting columns/piles need not be so thick and hence floor space in a building could be increased, or the size of civil works decreased, maximising space for other uses.

The strength of Aardelite is such that there may be concerns about its use in certain load bearing structures. Lytag concrete, however can be designed in accordance with BS 8110, Parts 1 and 2: 1985 *"The Structural Use of Concrete"* and be used for all normal reinforced, prestressed and post–tensioned concrete in multi–storey structures, pre–cast units, long span construction etc.

Pre–cast elements with lightweight concrete are easier to handle, have improved fire resistance, heat insulation (and frost resistance).

(b) *Economics*

Lightweight aggregate production has an associated cost (for capital plant, lime and energy) but these need to set against savings to be made in its use and the cost of quarrying alternative granite aggregates and of otherwise disposing of the PFA used in the manufacturing process.

Lightweight aggregate concrete is most economical when the dead weight is large compared with the total load and when a low density concrete is required. In these circumstances, the load bearing capacity will be the equivalent or even higher than normal weight concrete, as a proportion of the total loading. The reduced dead load can have a significant effect upon the cost of formwork and scaffolding (floor slabs, bridges etc.) and the saving of foundation costs in high rise structures and where bad ground conditions prevail, can be appreciable. In tall buildings, the dimensions of columns, particularly in the lower storeys, can be considerably reduced and generally an overall reduction in the amount of steel reinforcement required can be affected. Pre–cast elements in lightweight aggregate concrete are cheaper to transport and easier to handle on site which can result in financial savings due to reduced construction time. For example concrete block structures incorporating Lytag can be made much faster than those incorporating conventional dense concrete.

(30) Lytag (UK) Limited *"Lytag Structural Concrete – Guidelines on the Properties, Design and Specification of Lytag Structural Lightweight Concrete"* United Kingdom.

(c) *Environmental Issues*

By processing PFA into aggregate, a by-product of electricity generation is turned from a potential waste into a useful resource.

Other environmental benefits of lightweight aggregate usage are associated with the elimination of the need to quarry the granite that would otherwise have been used. Benefits would be in the form of reduced emissions/environmental impact and energy consumption at quarries and borrow areas.

Furthermore, a widespread use of lightweight aggregate could significantly reduce the overall volume of concrete mixed, with associate aggregates energy and environmental impact savings at cement works and at construction sites.

The environmental impact of the manufacturing facilities need not be significant as demonstrated at facilities in the USA (e.g. Aardelite plant at Christal River, Florida USA) given appropriate considerations during the planning process. However, such plants require energy and can be very dusty if proper measures are not instituted during the planning/design stages.

(d) *Market Potential*

The existing market for aggregates in Hong Kong is large. Currently, in concrete alone about 3.5 Mm^3/yr of aggregate and fine sands are used. Lightweight aggregates could theoretically replace much of this demand in standard concretes in granular (aggregate) or fines form (note of course if lightweight concrete were in widespread use the overall volume required would reduce by 10-25%).

The economic feasibility of a lightweight aggregate plant in Hong Kong would be mainly a function of:

- revision of government regulations to permit use;
- the plant capacity;
- land availability near to PFA producers;
- supply costs of PFA by utilities;
- market price of other aggregates;
- capital availability.

The latter, given government encouragement for a project, would most likely be the most uncertain. Experience elsewhere has shown that this type of project, whilst of overall benefit to society, does not usually happen unless either government, the utility company or both sponsor the operation.

(e) *Recommendation*

Despite some considerable potential in the long-term the Consultants do not see lightweight aggregate manufacture as a viable management strategy in the context of this study. We would however, recommend that government consider the option and potential benefits to the Territory. CLP suggest that a site for this, or other potential PFA utilisation plant, be set aside at Tuen Mun Port Development area. About 20-30 hectares would suffice.

3.2.5 *Manufacture of Autoclaved Aerated Concrete Blocks*

Autoclaved Aerated Concrete Blocks (AACBs), which can be cut, sawn and nailed, are manufactured from a foamed-lime/cement or PFA/cement slurry. They have the following properties that make their use an advantage over conventional building materials for certain applications:

- low density (whilst maintaining or increasing strength) making AACBs a lightweight alternative (only 25% the weight of ordinary concrete blocks the same size);
- good thermal insulation properties;
- efficient noise attenuation characteristics;
- improved finished surface, reducing the thickness of plaster required to provide a suitable painting surface by two thirds.

A manufacturing facility for AACBs is currently in the latter stages of construction (with commissioning anticipated soon) in Hong Kong at Yuen Long. The company concerned Daido Building Materials Limited, is a wholly own subsiduary of Daido Concrete (Hong Kong) Ltd, part of the Japanese based, specialised building-construction Daido Group. The manufacturing process is licenced to Daido Concrete by German based Ytong International Gmbh and, when the Yuen Long plant is fully operational, will produce over 100,000 m^3/yr of aerated concrete at the 2.5ha site.

Aerated concrete can be made using conventional concrete materials or could incorporate PFA (or FBA) - either as part of the TCC or aggregate content (in the form of lightweight aggregates).

Set up capital costs are estimated at HK$210 million with annual earnings expected to exceed HK$200 million. Negotiations between CLP and Diado were made to see if PFA can be incorporated to the benefit of both companies. Potential PFA use (as part of TCC) is estimated at between 5-10,000 te/yr. This would be a steady, continuous demand. However, under licence conditions from Ytong, Daido cannot use PFA in their block making plant.

The company anticipates market outlets in Hong Kong and export. Locally the Housing Department is seen as a potential major customer who could benefit from the material's advantages, derived from its lightweight nature, of reduced weight of walls which in turn, reduces the foundation loading and the cost of piling and foundation work, resulting in a significant reduction in overall building cost and construction time.

Benefits associated with the use of these blocks include reducing heat loss (or gain) from buildings. If used on a wide scale, AACBs could be responsible for slowing the rate of growth of electricity demand in the territory and the associated reductions in emissions of pollutants and by-product generation. Economic benefit to the Territory would acrue in the form of reduced fossil fuel imports.

Daido's plant is relatively small and significant use of aerated concrete will probably only occur if Government enacted building regulations requiring new buildings to meet minimum heat loss criteria. The necessary manufacturing plant to meet a large scale demand would need capital. The most likely way such a venture would work would be for Government or the utility generating companies themselves to subsidise the manufacturing plant. The utilities could perhaps divert monies that might otherwise be spent disposing of the PFA.

Possible environmental concerns would be those associated with PFA in concrete and potential environmental impacts associated with the manufacturing facility, neither of which need be of concern given appropriate management and planning.

Recommendation

In view of the obstacles described above and the newness of the product to HK, the Consultants do not perceive this as a viable PFA management strategy at this time. However, given financial backing by the utilities and encouragement by the authorities, the option may prove attractive at some later date. In this regard CLP advocate the setting aside of a site for an AACB plant close to ash producers in the Tuen Mun Port Development area.

3.2.6 PFA as an Interleaving Material at Municipal Landfills

PFA has been identified as a possible interleaving (or daily cover material) for municipal landfills. These landfills use large quantities of inert material to cover the tipping area at the end of each working day with a layer of a minimum thickness of 150mm. Interleaving material improves appearance and vehicle traction, reduces odourous emissions, access by insects and vermin, rainwater infiltration and windblown litter. Current sources of interleaving material are from:

- formation of landfills themselves in the form of topsoil and completely decomposed granite (CDG) from natural site slopes;
- inert material delivered to landfills, such as certain construction wastes;
- specifically imported inert interleaving material.

Use of PFA in municipal landfills has been carried out in the past, for example at Sutton Courtney Landfill, Didcot, UK and in Nottinghamshire, UK where PFA and domestic refuse are co-disposed. Field trials in Hong Kong were conducted at Pillar Point Landfill in the early eighties and results indicated that PFA satisfies the basic requirements for a daily cover material.

Three large new landfill sites are due to be constructed in Hong Kong; the SENT, NENT and WENT Landfills. Operators are yet to be appointed, and potentially large quantities of interleaving material would be required.

(a) *Economic and Technical Aspects*

PFA is an inert material, relatively simple to handle and its physical properties are similar to conventional CDG cover, provided it is kept damp (dry, it is a very dusty material), making it a potentially suitable replacement.

Economically, PFA could only compete with any shortfalls in interleaving material, i.e. that are not generated at or ordinarily delivered to the site. Hence, the viability of any scheme would initially depend on the relative costs of procuring and delivering either specifically imported or PFA fill.

UK experience has shown that a number of operational problems can arise[31]:

- Wet weather can lead to:
  - trafficking difficulties when cover depths exceed 100mm;
  - run-off of PFA from slopes of steeper than 1:10, particularly if left on the surface for longer than one day.
- Loss of dried out delivered PFA into the interstices of refuse can lead to under-estimation of cover requirements by up to a factor of 2.

Wet weather operational problems could probably be overcome by relatively simple procedures derived from experience at dedicated ash landfill sites (see *(b)* below). Loss of fill material into the interstices is also not seen as a problem where PFA would be delivered (and kept damp) as conditioned PFA or a dense slurry.

(b) *Environmental Aspects*

Environmentally the issues would, for the most part, be similar to those associated with dedicated PFA landfills (see *Section 3.3*), principally dust nuisance and potentially leachates.

We understand that the proposed new landfill sites will incorporate linings, leachate collection and treatment systems and would therefore discount any water quality impacts of heavy metal pollution and silty run-off due to PFA use. However, the treatment of the subsequent leachates may require particular attention if metal loadings were to increase significantly, in order to meet the required discharge criteria. Leachate analyses presented in *Section 2.3* do not indicate that the additional load would be significant in the context of the likely municipal leachate and the TM.

Loading rates and leachate quality are very important and are related to the way the waste degrades. Under normal conditions, landfilled waste degrades via an acidogenic phase in which complex organic acids are formed, followed by an acetogenic phase in which these acids are broken down to acetic acid, followed by a methanogenic phase in which the acid is converted to methane and carbon dioxide. Recently deposited landfill waste is therefore much more acidic than older waste.

(31) Aspinwall & Company Communication, *PFA Utilisation in Hong Kong,* J. Lucas to G. Dunn (CLP) (25 November 1991).

It has been suggested [31] that there might be benefits to the initial acidogenic and acetogenic phases of municipal waste leachate due to pH buffering afforded by alkaline PFA. The Consultants, however, can see no benefit in suppressing the degradation of waste by the maintenance of an acidogenic environment by buffering. This would lead to overproduction of long chain fatty acids, and acetic acid, with suppression of methanogenesis completely. Any gases produced would be those produced by the intermediate steps, i.e. carbon dioxide and hydrogen.

Monitoring at Sutton Courtney (which was a co-disposal site having a greater PFA mix with the waste mass than purely a daily cover application would) revealed a long term production of hydrogen that was attributed to PFA absorbing moisture and inhibiting gas progression to the methanogenic phase. Suppression of methanogenesis actually inhibits stabilisation of the waste, so therefore the problem of the waste is increased. Also, gas utilisation cannot be considered as the H_2 produced is an intermediate product, and therefore of uncertain longevity or rate of production. CH_4 on the other hand is the end of the degradation process and should therefore be encouraged. The presence of methanogenic bacteria actually inhibits H_2S formation due to sulphate-reducing bacteria, and so encouraging methanogenic conditions actually controls H_2S production (a toxic odourous gas).

It is therefore important to be able to proceed through to methanogenic conditions, to encourage gas and leachate production, and site stabilisation, to minimise long-term environmental problems.

The best course of action is to ensure that a daily cover of PFA remains sufficiently permeable to allow liquids to drain through it. If the pH can be maintained between 6.5 and 7.5 then no suppression of methanogenesis will take place. pH higher than this can be a problem. High pH values suppress methanogenesis and waste degradation generally by up to two orders of magnitude. This is not good operating practice. Leachate recirculation may be a viable method of regulating pH if the PFA starts to kick the site into alkaline conditions. Whilst co-disposal, as at Sutton Courtney, would not be recommended in view of the above we feel that daily cover gives a different chemical environment than co-disposal since the mix is less intimate and potentially should not give rise to intractable problems.

Some concern exists over the potential for PFA to undergo a reduction in permeability upon contamination with leachates. A principle requirement for materials used within a landfill site is that passage of gases and liquids remains relatively easy, such a demand thus reduces the attractiveness of PFA as an interleaving material. However, further research using leachates from Hong Kong landfills, and examining leachate drainage means via alternative conduits, such as in-built gas wells, may overcome this potential drawback.

Dust nuisance could arise in the transport, deposition, and spreading of PFA, in addition to wind entrainment of placed material. The following measures have been shown to mitigate these concerns with PFA:

- Transport and handling of ash in conditioned (or alternatively as a dense phase slurry) form;

- Immediate spreading and compaction on delivery to prevent the formation of loose stockpiles that could dry out;

- Sprinkler systems to wet areas where dust might or does arise (this also requires a reliable dust monitoring system and the minimisation of plant movements).

Previous filling works using PFA at Area 47S Tuen Mun, Siu Lan Shui and Pillar Point Landfill(22) using PFA in conditioned form have demonstrated that operations can be carried out without any significant dust problem and there is no reason to see why application at other landfills should be any different.

(c) *Market Potential*

The study has discounted existing landfills since these will already have secured interleaving fill or will have a remaining capacity so small to be of limited or no relevance to the LTPS. Further, the quantities of construction waste (a proportion of which can be used as daily cover) being produced in the Territory at present are greater than current requirements at up to 16,000 te/month, although this is not expected to be the long term situation.

Of the proposed landfills WENT is by far the most attractive outlet for PFA from CLP's coal-fired TPS's, due to its proximity to CLPs utilities and the likely shortfall in landfill interleaving material. The requirement for interleaving and cell construction materials may be expected to be in the order of 10% of the waste input to the site. Thus in 1996 a potential consumption of between 450–700 tonnes/day could result, with a mean usage of approximately 750 tonnes/day (0.27 Mte/year or 5.4 Mte total over the 20 year period from 1996 to 2016). In addition, there is a requirement for approximately 5 Mm^3 of reclamation fill of which 2 Mm^3 could be met by PFA currently in the adjacent Tsang Tsui Lagoons. These figures are very dependent on forthcoming waste management studies and decisions, but serve as a useful indication of the quantities involved. Transport to the site could be by a number of means; truck, conveyor (enclosed belt, pneumatic, screw etc), pumped dense phase slurry or barge; all of which would be cost effective compared to the alternative of winning materials from borrow areas. Transport in the form of a dense phase slurry, with little free water, might allow direct spray application, reducing the number of times the material must be handled to a minimum. Assuming that an operator would accept PFA and that CLP supply this at cost, then on economic grounds, the option appears favourable.

Preliminary studies for the SENT landfill(32) indicate a total fill requirement of $18Mm^3$ for site preparation and operation. Of this, approximately one half is expected to be won on the site or provided by incoming construction materials. The remaining $9Mm^3$ of material will be required to fulfill the ongoing programme of site formation works as well as materials for cell construction and interleaving purposes. The site is expected to have a life of approximately 13 years (1994 to 2007) with a mean fill rate of 7,000 te/day. Of the anticipated interleaving and cell construction requirements approximately one half may be found on site, leaving an opportunity for approximately 350 te/day or 0.128 Mte/yr of PFA to be used. Thus the potential use of PFA at SENT for operational purposes from 1996 to site completion would be in the order of 1.5Mte, plus the potential uses as a fill material (in the order of $3Mm^3$). The most sensible form of transport by CLP would be by barge to the site, the cost of which would compare favourably with alternative materials (at about HK$25/te).

(32) Scott Wilson Kirkpatrick in association with Aspinwall & Company *"SENT Landfill Study, Final Report Executive Summary"* (March 1991).

The NENT landfill is not perceived as being a likely market for CPPS or LTPS ash, since it will win most of its fill requirements from site formation. Discounting, for the time being, the prospects of further future landfills, a total regular amount of PFA of about 0.4 Mte/yr or 6.9 Mte could be utilised in fills by 2016, with additional $8Mm^3$ for fill material, if the demand can be met.

(d) *Strategies and Recommendations*

The amount of PFA that could be utilised as interleaving material in the SENT and WENT landfills is significant in terms of the overall production of PFA from the TPSs. The specification for the Privatisation of WENT Landfill states that PFA may be used as an alternative cover material. However, the contractor has to demonstrate to the Independent Consultants and the Employer that PFA is a satisfactory material for daily cover. Certain technical and economic areas require further consideration, but there would appear to be no major environmental constraints to the use of PFA.

3.2.7 *PFA/Bentonite Mix as a Lining and Capping Material for Municipal Landfills*

PFA, when mixed in appropriate proportions with bentonite forms an impermeable material with self healing properties, mechanical strength and erosion resistance. This material has been identified as a potential liner or capping material for Municipal Landfills.

The WENT landfill will require approximately 110 ha of liner material, which depending upon the design chosen could utilise between 300 and 600mm of a bentonite/soil admixture. The proportion of bentonite to soil can vary between 5 to 15% dependent upon the material specifications; it is understood that a 12% bentonite component is currently required for the Advance Works presently underway. Subject to further trials, a lower proportion of bentonite to PFA may provide the required liner characteristics. Discounting that already laid by the Advance Works Contract (approximately $33,000m^3$) potential exists for the utilisation of approximately 297,000 to $627,000m^3$ of PFA/bentonite admixture. Assuming a bentonite component in the order of 7% the PFA requirement is then 276,000 or $583,000m^3$, which will be a progressive demand. Similarly the cap design may incorporate a 300mm thick layer of the admixture which would equate to approximately $360,000m^3$ of PFA.

SENT landfill, assessing similar liner and cap design options will give a potential PFA usage of approximately $168,000m^3$ or $338,000m^3$ for the liner system and an additional volume of approximately $300,000m^3$ for the cap.

As mentioned earlier suitable trials would be required to determine the most appropriate mix, and the viability of total replacement of the 'soil' component with PFA.

For the NENT landfill the potential use of a soil/bentonite liner design would be restricted to the base area, and would require 38,500 or $57,000m^3$ dependent upon the thickness chosen. Again, assuming a bentonite component of 7% this would represent a PFA demand of $26,500m^3$ or $53,000m^3$ respectively. However, the cap design may incorporate a similar system which could utilise approximately $200,000m^3$ of PFA in its constriction.

3.2.8 *PFA as a Soil Ameliorant/N-Viro Process*

PFA can be used directly as an ameliorant to improve both sandy and heavy clay soils, although potential quantities that could be used in Hong Kong in this way are not considered significant in the context of this study.

Of greater potential is the incorporation of PFA in the N-Viro Process to produce a synthetic soil in combination with other waste materials such as sewage sludge, water and wastewater treatment sludges, livestock manure, cement kiln dust etc. Such soil could potentially be used beneficially in agriculture, land reclamation, and as a interleaving material at municipal landfills, in addition to the final 'topsoil' layer in the cap.

Section 3.6.6 discusses potential uses of PFA as an interleaving material and concludes that whilst it may be a suitable material, certain technical issues would require resolution. The product soil from the N-Viro Process would not give rise to technical constraints in terms of its handling characteristics as a cover material and in addition to utilising PFA, beneficial use could also made of other waste materials.

(a) *The N-Viro Process*

The N-Viro process was developed in the USA as a means of stabilising municipal sewage sludge to provide a product of agricultural value. The process has been accredited with an US EPA (Environmental Protection Agency) certification as a "*Process to Further Reduce Pathogens* (PFRP)"[(33)].

The stabilising agent is an alkaline ad-mixture; cement kiln dust (CKD) and quicklime (CaO) have been employed. The process has applications outside of this specific mixture and other sludges, including those from water and wastewater treatment and livestock manure could be stabilised with alkaline admixtures made up of PFA, CKD and perhaps other industrial wastes like steel works filter dust in combination with lime.

Processing involves dewatering sludges to between 18 and 40% dry solids in, say, a simple belt press and mixing with the alkaline admixture in a pug mill or screw blender to produce a granular, easily handlable soil-like material. The pH of the mixed material would initially exceed 12 and the exothermic reaction of the alkaline additives with the sludge would produce enough heat to raise temperature above 50°C which reduces the pathogenic microbial population in the sewage sludge to below the US EPA's PFRP standard in about 12 hours, without completely sterilising the final mixture.

Typical mixing proportions are 50-60% sludge, 30-35% alkaline waste and 5-10% lime. This compares with proportions of 50% wastewater treatment sludge filter cake, 20% alkaline waste and 30% lime use in a typical chemical waste stabilisation plant to produce a cementitious, leachate resistant stabilised sludge[(34)]. After pasturisation (heat treatment) the treated sludge is air dried (while the pH remains above 12, for at least 3 days) until solid levels reach a minimum of 50% dry solids. The temperature at which pasturisation is conducted effectively kills pathogens whilst retaining soil-like indigenous

(33) Logan, T.J. (Dr), "*Potential Markets for N-Viro Soil*" Professor of Soil Chemistry, Agronomy Dept, Ohio State University.

(34) Stephanatos, B.N., MacGregor, A., "*Stabilisation and delisting of Hazardous Wastes: An Effective Approach for Reducing High Sludge Disposal Costs*", presented at HMCRI's Hazardous Materials Control '91 Conference, Washington D.C., USA (December 1991).

microflora. After two years the level of bacterial microflora in US tests was nearly equal to that found in a typical agricultural soil. Product "soil" is claimed to be odour free.

The initial high pH of N–Viro soil is claimed to be rapidly reduced in soil because of the small quantity of strong alkali component present in the lime which is quickly neutralised. That the majority of the lime is in the form of calcium carbonate, the same ingredient in agricultural limestone, would tend to confirm the above.

Sludges can contain significant amounts of toxic metals. The increase in pH of the sludge in the N–Viro process results in significant reduction in toxic metal solubility. Tests in the US using an EPA toxicity method showed that even at relatively low pH (5–7) leachate from the soil did not exceed US EPA limits. Hence, whilst addition of admixture treated sludge to a typical soil increases the total metal content, the availability or extractability of toxic metals is reduced upon addition of treated sludge to the soil at a given pH.

The product is claimed to have the following physical properties:

- excellent physical handling;
- low odour and low odour potential;
- stability under storage;
- acceptable appearance;
- readily spreadable with conventional earth moving equipment.

(b) *Potential Application in Hong Kong*

Hong Kong produces, or will produce over the lifetime of the LTPS, significant quantities of:

- sewage sludge;
- water treatment sludge;
- wastewater treatment sludges (including those that may arise at the LTPS;
- livestock and poultry manures.

The disposal practices for these wastes are not without environmental impact, either involving dissolution and discharge to the marine environment or treatment followed by landfilling. Quantities of sewage sludge at 135 te/day in 1988[(21)]) will rise dramaticly as planned secondary sewage treatment works come on line (to an estimated 560 te/day in 2001). Water treatment sludges (produced at a rate of about 4,000 te/day in 1988[(21)]) have in the past, been dumped at sea, but are in the future more likely to become feed to sewage treatment works.

Marine dumping, via boat or submarine pipeline is currently effected for much of these sludges, but is not seen by the authorities as necessarily the best long–term option for disposal. Further, there are areas where sludges arise, or will arise that are sufficiently far from a suitable waterfront to necessitate disposal to landfill[(21)]. Wastewater treatment sludge production is anticipated to grow rapidly with the enforcement of the TM for effluent discharges. Currently the only planned disposal route would be via chemical stabilisation at the Chemical Waste Treatment Facility (CWTF) and then, landfilling.

The N–Viro Process offers the potential of rendering a proportion of these sludges in a more stable and environmentally acceptable form, whilst also consuming significant quantities of other solid wastes to produce a material useful to the Territory.

The means by which the process could be instituted in Hong Kong would require political will on behalf of Government to enact the necessary regulatory measures or create appropriate market conditions, and co–operation of the waste producers. There are areas where the process could be particularly applicable. For example, in the NWNT all the components are situated in close proximity:

- The proposed NWNT sewage works at Leung Kwu Sheung Tan will produce large quantities of sewage sludge (mixed with many tonnes of water treatment sludge) destined for disposal at a landfill (probably WENT).
- CLP and other developments in the TMP area may be producing quantities of wastewater treatment sludges.
- CLP, CCC, and Shiu Wing will all produce quantities of alkaline dust or ash requiring an outlet to disposal facilities or otherwise.
- The WENT landfill has a significant need for imported interleaving material, in order to reduce reliance on the borrow area.
- Proposed reclamations and developments in the area will provide land for any N–Viro facility, and would require large quantities of top soil for landscaping purposes.

An N–Viro Processes facility located in the area could potentially help solve several problems. The environmental benefits are potentially significant whilst impacts should be minimal given appropriate planning and control. The only major drawback is the additional cost of producing the N–Viro product compared with raw PFA. However, it must be remembered that the N–Viro process is also utilising another difficult waste, sewage sludge, and likely producing an acceptable product from two less acceptable ones.

Section 3.2.6(b) discussed the potential adverse effects to municipal waste degradation arising from the raised pH of leachate from PFA used as an interleaving material. These concerns are also associated with N–Viro soil. However, the greater permeability and limited alkalinity of N–Viro soil should aid resolution. However, as with PFA, this would need further study and trials to confirm suitability. Further, incorporation of sulphate containing FGD wastewater treatment sludge into the N–Viro process would merit testing to confirm the sulphate would not be available, leading to the production of H_2S.

(c) *Recommendation*

Whilst the possibilities outlined above may appear speculative there is a considerable potential to beneficially utilise several wastes together. Further study would be required in respect of technical feasibility, environmental and economic impact together with likely supply and demand. The use of PFA as a soil ameliorant or admixture in the N–Viro process cannot be considered a reliable management strategy at this time, but would appear to have considerable potential.

3.2.9 *Use of PFA as a Reclamation Fill*

PFA can be used as a fill in a variety of applications, such as a structural or bulk fill, restoration and landscaping fill and as a land reclamation or site formation fill. It is reclamation that has the most potential for a utilisation strategy in Hong Kong over the LTPS lifetime and hence, the study has concentrated in this area. Foreseeable Territory wide fill material requirements exceed 15 Mm^3/yr (up to 2001)[(3)] well in excess of the entire territories PFA production (see *Section 2*). This fact has not gone unnoticed by CLP who have been conducting trials and an aggressive marketing campaign for over 10 years to show that PFA is a suitable fill material on technical, economic and environmental grounds and if used in sufficient quantity the problems associated with its permanent disposal would cease to exist.

There are two principal areas where fill is required:

- Inland site formation and above water level sections of foreshore reclamations;
- Underwater fill for foreshore reclamations.

Co-ordination, review and collation of information on sources of fill for prospective projects within Hong Kong is carried out by the Government's Fill Management Committee (FMC), chaired by Civil Engineering Services Department with environmental advice from EPD. The FMC's responsibilities include *"the co-ordination of the supply and demand for Pulverised Fuel Ash (PFA) for use as fill material"*[(35)].

Historically, fill material in Hong Kong has comprised rock and soft fills taken from hillsides and quarries. More recently, as supplies of these fills have become more scarce, the favoured material has been marine dredged sand taken from the seabed around Hong Kong. Recent projections by the FMC indicate that dredging could be required in some more environmentally sensitive areas such as Deep Bay and Mirs Bay.

Currently, active Government approval (via the FMC) for the use of PFA as a reclamation material is only given for above water level sections of reclamations, although this situation is changing, with FMC actively seeking ways to utilise more PFA in Government contracts so that the need to construct further PFA disposal facilities can be avoided.

Worldwide use of PFA as a reclamation fill has mostly been confined to on land usage since there are few countries where land or disposal sites are at such a premium as in Hong Kong (an exception is Japan and limited experience in the UK - see below). There are numerous examples of PFA disposal facilities being restored for light agricultural or recreational use. There have however, been few examples of the use of fly ash in below water level reclamations. Most underwater uses have involved mixing with cement to cast units for breakwaters or artifical reefs. However the Japanese have done some work on reclamation applications. The Coal Mining Research Centre (in association with the Electric Power Development Company Ltd., Hokkadio Electric Power Company Inc and Mitsui Construction Company Ltd) market a system for non-diffuse and high density application (or "tremmie placing") of PFA as an underwater land reclamation material which is believed to have been employed in the Tokyo and Osaka

(35) Works Branch Technical Circular No.6/89, *"Fill Management"*, ref. WB(W) 209/32/96 (89)II, (18 October 1989).

areas of Japan[36].

In Hong Kong several major projects have used PFA fill in site formation, marine and marsh reclamation and CLP have used these opportunities to conduct technical and environmental tests.

- *Siu Lang Shui PFA Landfill*: In the early eighties CLP used 410,000 te of PFA to demonstrate the use of PFA as a site formation material[37],[38].

- *Tuen Mun Area 2A*: Between 1984 and 1987 over 200,000 te of conditioned PFA was used in five separate infrastructural projects in Tuen Mun New Town to form sites for construction of housing estates, a school, police and fire stations, access roads, LRT tracks and highway interchanges (for example contract No's TM29/84, TM36/85, TM33/84 and 998190/84).

- *Tuen Mun Area 47S*: In 1988, 50,000 te of PFA fill was used as an alternative to soft fill, to reclaim a seafront intertidal area at Pillar Point for later industrial development.

- *Eastern Harbour Crossing*: In addition to utilising PFA in concrete for the tunnel sections (*Section 3.2.3*) over 15,000 te was used as an underwater marine fill to reinstate seafrontage at both ends of the tunnel (9,000 te at Quarry Bay and 6,000 te at Cha Kwo Ling). Advantage was taken of the lightweight properties of PFA fill compared with completely decomposed granite (CDG)[39],[40],[41].

- *Tsang Tsui Ash Lagoons*: CLP PFA surplus to current demand is stored in ash lagoons at Tsang Tsui. Currently about 2 Mm^3 (approx, 2 Mte) are held, mainly in the West lagoon. Investigations conducted by CLP have provided data for assessing the characteristics of PFA as an underwater fill[42],[43]. The area has been preliminary zoned for industrial development post 2011 and the full lagoons would be the base of the reclamation.

- *Marsh Reclamation:* PFA has been used to reclaim a marsh area at Ha Tsuen, New Territories and for fish pond reclamation near Hung Shui Kiu, New Territories to successfully form sites for development.

(36) IEA Coal Research *"Applications for coal-use residues handbook", advanced excert* by Fax from Dr Lee Clarke (6 Aug 1991).

(37) Gammon (Hong Kong) Ltd., *Castle Peak 'B' Power Station, PFA Disposal – Siu Lang Shui (Laboratory Test Report),* for CLP (1985).

(38) Gammon Construction Ltd., *PFA for Tsang Tsui Ash Lagoon (Laboratory Test Report),* for CLP (1989).

(39) Binnie Consultants Ltd., *Pulverised Fuel Ash as a Reclamation Fill,* for CLP (1990).

(40) Freyssinet Hong Kong Ltd., *Eastern Harbour Crossing at Quarry Bay (Site Formation Report),* for CLP (1989).

(41) Freyssinet Hong Kong Ltd., *Cha Kwo Ling (EHC Site Investigation Report),* for CLP (1989).

(42) Freyssinet Hong Kong Ltd., *Upper Level of the Ash Lagoon at Tsang Tsui (Site Investigation Report),* for CLP (1989).

(43) Gammon Construction Ltd., *Castle Peak 'B' Power Station, PFA for Tsang Tsui Ash Lagoon (Laboratory Test Report),* for CLP (1989).

(a) *Economic and Technical Aspects*

(i) *Geotechnical Properties*

CLP arranged trials and geotechnical tests on PFA reclamations have shown that PFA satisfies the technical requirements of a reclamation fill. A report entitled '*Pulverised fuel ash as a Reclamation Fill*'[39] concludes

> *"... PFA will consolidate quickly when placed in a reclamation site. The strength parameters of PFA are comparable to those of a silty sand which render it a good foundation material. The compressibility of PFA fill depends upon the method of placing it. Mechanically placed ash has a compressibility comparable to medium dense to dense CDG, whilst the compressibility of hydraulically placed ash is somewhat higher. Since PFA is a lightweight fill, it imposes relatively low loads on buried structures.*
>
> *PFA is therefore as good if not better than the soils commonly used in Hong Kong for reclamation fill."*

Indeed the lightweight and pozzolanic properties of PFA can offer advantages in reduced earth settlement and lower earth pressures against retaining walls as demonstrated, for example, at the Eastern Harbour Crossing.

However, these properties also create difficulties in areas of reclamations that require surcharging, such as areas for culverts or roads. It has been indicated to the Consultants that the level of surcharging required, if marine muds are left in place, would be higher with PFA fill. For areas other than for utility purposes, surcharging is not usually necessary.

PFA could be mixed randomly with other sources of fill in a reclamation which means that the rate of filling of a reclamation need not be governed by the rate of supply of PFA. For buildings supported on piles or for reclamation using hydraulically placed marine sand fill then random mixing of PFA would be acceptable. If PFA were to be used randomly with as - dug rock material more selective filling would be desirable.

(ii) *PFA Supply*

Most reclamation projects in Hong Kong are performed on a large scale and typically large volumes of fill are required over a short period. PFA production at CPPS and at the LTPS would be approximately 9,000 te/day by 2016 assuming *Scenario I* firing at the LTPS. Maximum production rates to date have been about 4,000 te/day. These production rates coupled with CLP's primary strategy of utilising PFA in areas where there is a steady continuous demand, such as in cement and concrete, mean that direct use of available PFA would suit only small sized reclamations or where the PFA was comingled with other fill materials. However, usage of Tsang Tsui ash lagoons or dedicated landfill sites as a temporary storage facility for excess PFA would likely allow several small to medium sized reclamations to be completed each year with PFA or a substantial contribution to be made to larger reclamations.

(iii) *PFA Storage & Harvesting*

PFA could be stored, or lagooned in conditioned or drained slurry form at either Tsang Tsui or another dedicated site such as Siu Lang Shui. The problems associated with accumulating material in this way are the cost of double handling and the environmental impacts.

In the UK at Kingsnorth, a harvesting operation for the CEGB (Central Electricity Generating Board) on the North Kent Coast by the River Medway was conducted by Van Oord Dredging company[(44)] and involved harvesting 550,000m^3 from full ash lagoons (combined PFA and FBA), pumping about 1km to hopper barges off the lagoons and subsequent transport about 4km to a second pumping station adjacent to a bunded foreshore reclamation area at Lappel Bank. The reclamation of the 21 hectare site was for the Medway Ports Authority and dry/conditioned ash from storage bunkers and stockpiles at the site were also used, although this ash was transported by truck.

Presently 2 million tonnes (equivalent to 2 Mm^3) of PFA are stored at Tsang Tsui in the lagoons. This material could be reclaimed by dragline, dozer or by reslurrification (cutter suction dredger) as was the case at the Kingsnorth lagoons. Transfer to reclamation sites could then be affected by barge, dredger or, if close enough (within a few km) by pipeline. This process would have an associated cost but could extend the life of the lagoon substantially or even indefinitely. Alternatively, fresh conditioned ash could be stockpiled on top of the existing material to create a readily handleable reserve.

Landfill sites, located within easy reach of both power stations, for storing PFA for subsequent retrieval are possible as an alternative to continued use of the lagoons. Further advantages would be afforded by good road and marine access. However, environmental issues would need detailed study at any selected site.

(iv) Economics

CLP's current intent is to make available its PFA at cost, although the particular reclamation project would be expected to bear the cost of transporting (and havesting if necessary) the PFA.

Discussions with FMC prior to issue of the Initial Assessment Report[(3)] indicated that the use of PFA in planned projects would prove economically attractive. CLP's previous experience has indicated that PFA is an economical alternative to conventional fills.

According to recent CLP studies, average costs of placing PFA are some 40% lower than those for conventional fill materials (mainly due to the free supply of PFA from CLP). Another study for the Tuen Mun Port Development[(45)] assesses the costs of various fill materials. Land based fills cost from HK$40–45/m^3 of placed material, marine dredged sands were expected to cost about HK$35/m^3 whilst PFA would cost about HK$12/m^3 placed material (note the transportation distance is very small in this instance).

The economic implications of harvesting PFA from storage at Tsang Tsui have not been assessed in detail, but for supply of PFA material to WENT landfill reclamation as a seawater slurry costs for transportation and harvesting should compare favourably with those for alternative materials. It could be expected that to accumulate conditioned PFA at Tsang Tsui ready for barge loading would be more expensive, but still less than that of alternative materials.

(44) Van Oord Dredging (UK) *"Kingsnorth Power Station, Sheerness–Pilverised Fuel Ash Transport".*

(45) Scott Wilson Kirkpatrick *et al., "Tuen Mun Port Development Study Working Paper No.11, Dredging, Filling & Reclamations"* for Territory Development Department, Tuen Mun Development Office.

(b) *Environmental Aspects*

The environmental benefits of utilising PFA in reclamations are similar to those associated with other beneficial uses, namely elimination of the need to dispose of large volumes of waste material, energy savings associated with the acquisition of alternative fill materials and the secondary environmental benefits associated with leaving these materials in place (e.g. marine sands, soft and rock fills).

(i) *PFA Placed on Land*

A recent report commissioned by CLP to look at the environmental aspects of PFA utilisation[22] identified six areas where environmental concerns had been indicated for PFA placed on land. These were leachate, radioactivity, occupational/public health, dust nuisance, plant pollution and erosion. The report drew on latest information available internationally and locally, in particular from CLP's own research and monitoring programmes.

The report concluded that none of these areas need give rise to significant environmental impacts provided PFA is used in conditioned form and routine site management measures are followed. Typically about 1m of CDG is placed on top of PFA fill as a capping layer, to mitigate dust problems. This is in line with current GEO and EPD encouragement of the use of PFA in site formation and the results of trials and tests conducted at previous site formations in Hong Kong (see also *(ii)* below).

(ii) *PFA Placed Underwater*

The introduction to this section cites three 'underwater reclamations' conducted using CLP's PFA in Hong Kong. Monitoring during the construction of these reclamations, and that on-going, has not indicated any significant environmental impacts. Two methods of underwater placement have been practiced in Hong Kong:

- Placement of conditioned PFA by grab handlers direct into a bunded area confined by seawalls protected on the landward side by a geotextile fabric (Typar 3857) (e.g. Eastern Harbour Crossing).

- Hydraulic (above waterlevel) placement of raw PFA into purpose built lagoons as a seawater slurry (Tsang Tsui ash lagoons).

A Japanese consortium advocate a pontoon based underwater injection placement system[36] which injects a PFA/Seawater Slurry into a sedimentary layer of coal ash on the seabed. They claim their system prevents marine pollution of the sea to reclaim land with a high load bearing strength (0.5 - 1.0 kgf/cm^3 after 20 days unconfined compression).

With both of these methods areas of environmental concern are essentially similar, being leaching of heavy metals, siltation and radiological impacts in dwellings built on the reclaimed land. Issues related to dust nuisance and PFA floaters (small glassy spheres with a specific gravity of less than 1) have been discounted by recent studies as mitigable with simple site management practices[39],[8].

Leachate

A study[8] was recently commissioned, as part of the SENT Landfill study, by EPD to look specifically at the issue of leachates from underwater reclamations using PFA. Extensive trials were conducted to investigate the potential for 11 toxic metals to be leached into the marine environment off Tseung Kwan O (see *Section 2.3)*. Both PFA from Tsang Tsui and direct from the precipitators were analysed showing, as might be expected, more metals were leached from fresh PFA than that weathered at Tsang Tsui. An attempt was made to relate the expected 'volume' of leachate to those set out in the *Technical Memorandum on Effluent Standards*[46] and associated discharge concentration standards.

It should however, be noted that the TM specifically excludes runoff from landfills and reclamations in paragraph 2.4 with the words *"Nor does it (the TM) apply to dredging, dumping for land formation or solid waste disposal"*. The study found that in the 'worst case scenario' only the concentration of cadmium is likely to approach or exceed the guide value. No other discharge standard would appear to be at risk of being breached. (The discharge standard for cadmium is extremely stringent, even for industrial effluents, at 0.001 mg/l.) In respect of lagooned PFA the study concludes:

> *"... subject to good construction and reclamation procedures, no unacceptable environmental impacts would result."*

On-going monitoring of seawater adjacent to Tsang Tsui ash lagoons, both prior to construction and during operation, has shown that whilst concentrations of trace metals fluctuate, no significant long term increases in concentrations of sensitive metals have been linked to the operation of the PFA lagoons (see *Section 2.3)*. Further evidence on the effects of PFA on the aqueous environment is given in another recent study[22] which concludes:

"• *only minute traces of environmentally significant elements (heavy metals) are likely to be released from PFA*

• *any such release is likely to be so small that, under normal conditions, natural dilution will disperse it without significant affect on the environment*

• *there are already dissolved heavy metals in local waters, in the local sediments and in the local biota; any increase resulting from PFA utilisation is likely to be insignificant if, indeed it is even measurable"*

On the basis of the above referenced studies and a review of the contained data therein, we can see no impediment to the use of PFA in underwater sections of reclamations in respect of leaching of toxic metals.

Further, there appears to be no requirement on the basis of environmental impact for the use of impermeable or semi- permeable membranes on the seawalls around such reclamations, except when a reclamation is planned for an area with a particularly sensitive local marine environment or within, or close to, mariculture zones. Geotextile fibre should be placed around the outer seawalls of a PFA reclamation to prevent migration of "fines" to open sea where there is a likelihood of PFA escape to an environment sensitive to raised levels of suspended solids.

(46) EPD, *"Technical Memorandum, Standards for Effluents Discharged into Drainage and Sewerage Systems, Inland and Coastal Waters"* (January 1991).

Siltation

The prospect of siltation of PFA beyond any reclamation area is not possible when the area is fully enclosed by adequate seawalls. Use of barge bottom dumping of PFA in partially enclosed reclamations, as practiced with other fills, could give rise to siltation on the seabed beyond the immediate dumping/reclamation area depending on tidal flows and site specific arrangements. Such siltation would be preceded by raised levels of suspended solids and could lead to sterilisation of the seabed in the vicinity of the reclamation. Appropriate design of seawalls and site management practices could prevent siltation in most instances.

Radiation

As with the use of PFA in concrete, concerns have been raised in the past over radiation emanating from PFA in reclamations and the accumulation of radioactive radon gas in the basements and lower floors of buildings built on PFA reclamations. The origin of these concerns were explained in *Section 3.2.3(b)*.

In south-west England, high concentrations of radon gas have been measured in the living accommodation of homes, and public places such as schools and libraries, where open earth floors or suspended wooden floors without free air circulation beneath have allowed radon gas to accumulate.

The solutions used, incorporate both active and passive methods of radon protection. Passive methods, favoured in dwellings, include routing of all services through the side walls and not the base of the building structure. Membranes comprising up to 2mm thickness HDPE, interlaced with the damp course and covering the whole of the base of the building, act as a retardation barrier to radon ingress, but must be designed so as to stop gas migration up cavity walls into higher living accommodation. Active methods, always additional to the above, include forced air circulation in the air space voids beneath buildings to flush any air arising from the ground beneath the building. Active methods are only recommended for buildings where some degree of institutional monitoring is available and are therefore not recommended for use in private dwelling.

As detailed in *Section 3.2.3(b)*, the radiological properties of PFA are broadly similar to that of CDG prevalent throughout Hong Kong. Provided suitable barrier methods are used to prevent radon accumulation in dwellings, the risk to residential buildings constructed on PFA reclamations (or indeed anywhere in Hong Kong) can be ignored.

The use of open floors or enclosed suspended flooring is currently a rare practice in Hong Kong and is generally only likely to be found in squattered wellings. However the Consultants recommend that no such construction be undertaken without adequate underfloor ventilation for any residential buildings constructed in Hong Kong, including those on PFA reclamations.

The use of barrier methods to prevent radon ingress should be recommended wherever such a risk exists.

(iii) *PFA Storage and Harvesting*

Section 3.2.7(a)(iii) indicates PFA would be harvested from lagoons at Tsang Tsui using a pipeline, pipe conveyor or mechanical conveyors, incorporating a minimal amount of added water, to barges off the seawall. Use of a macerator suction dredger (or cutter suction dredger) in the lagoons has been suggested. The lagoons already possess the necessary equipment to mitigate dust emissions with water sprays if necessary. Pipelines and pipe conveyors are enclosed and can be designed to transport dusty materials with minimal environmental impact. Mechanical conveyors would likely transport the material in conditioned or dewatered form which would eliminate wind entrainment of PFA. Some mechanism would be required to ensure any free water transported to the barges with the ash did not overflow into the open sea. Pumped return to the lagoons would suffice.

Conditioned or stockpiled PFA would require more careful handling to ensure the minimisation of windblown dust, but adequate facilities are thought to be available at Tsang Tsui to ensure this.

Storage at other sites would need to be handled with care to avoid dust and measures may need to be taken to avoid contamination of adjacent watercourses with PFA washed out from the working site. A collection system incorporating perimeter drains around the landfill would suffice (see also *Section 3.4*).

(c) *Market Potential*

As indicated in the introduction to this section, the demand for reclamation fill, in the next decade at least, far outweighs the maximum envisaged production of PFA for the Territory as a whole, as illustrated in *Figure 3.2(a)* overleaf. Demand beyond this period also appears to be high with PADs related projects due to proceed until 2011 and demand for residential land is proceeding in line with growth in electricity demand and hence ash production rates.

CLP state that over 2 million tonnes of their PFA have been used to date in reclamations and site formation of over 40 hectares of land in Hong Kong, China and Macau, with much of this in marine reclamation[7],[39].

FMC, GEO and EPD recently approved the use of about 150,000 tonnes of PFA for a marine reclamation for Urmston Road Sewage Outfall in Lung Kwu Sheung Tan Bay. Discussions are underway by CLP's Ash Marketing for the use of 2,250,000 tonnes at either the SENT or WENT Landfill and less definitely regarding the use of PFA at the new airport and North Lantau Expressway. Further the proximity of proposed reclamations at Tuen Mun Port to CLP's power plants will make the use of PFA particularly economically favourable if timing permits. Recent studies for TMP have confirmed both the PFA fill requirement and economic advantage[45].

There would appear, therefore to be no reason why all surplus PFA could not be used within the Territory's reclamations. For this to be achieved however, Government would need to actively encourage its use and certain existing restrictions on its use would need to be lifted. CLP would prefer all government contracts to specify the utilisation of PFA to the extent that it was available.

(d) *Strategy and Recommendations*

Past experience in Hong Kong and elsewhere have shown that there are no major impediments to the widespread use of PFA in site formation and marine reclamation projects on the grounds of technical feasibility, geotechnical properties, and economic and environmental grounds.

The approval of the use of PFA at Lung Kwu Sheung Tan for a working area for the NWNT Sewerage Outfall and consultations conducted as part of this study, indicate that Government thinking on the use of PFA as a marine (underwater) reclamation fill may change in the near future. For example:

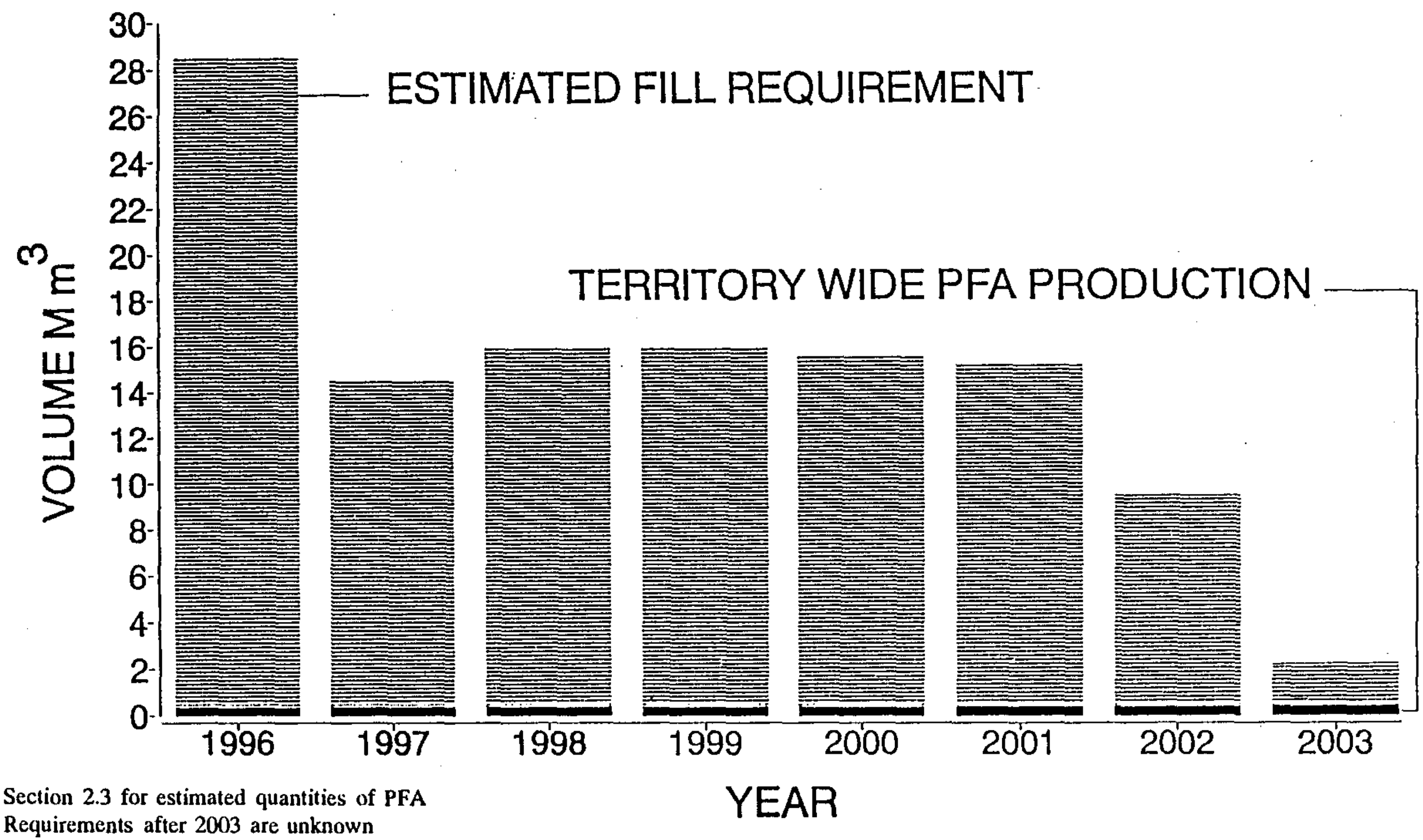
- GEO confirmed that the use of PFA as fill below water at the small reclamation area at Lung Kwu Sheung Tan (to be formed as a staging area by the NWNT Outfall Contractor) has been endorsed by the Fill Management Committee. The matter is now subject to finalisation of the contractual arrangements between PM/NWNT and the Contractor. This work will commence shortly, and EPD and GEO will be involved in the environmental and engineering monitoring of the trial.

- There are two Government initiatives that might make more use of PFA, one is that Government is now much more sympathetic towards the wider range of use of PFA, the second is that Works Branch, Housing Authority, and EPD were looking into the greater use of PFA in Government projects (which has implications for concrete use as well).

Successful completion of the Lung Kwu Sheung Tan reclamation should open the way for widespread use of PFA as an underwater fill. This will address the remaining environmental concerns and hence help to realise the environmental benefits of utilising, rather than disposing of PFA.

The Consultants would recommend active Government encouragement for use of PFA as a reclamation fill. CLP would advocate the mandatory use of PFA in reclamations when it is available in sufficient quantity, with particular emphasis on any reclamations within reasonable transportation distance of the Power Stations where transportation costs would be lower, further enhancing the economic advantages of using PFA. Procedure was set for this in the mid eighties with the spec. of PFA use for the Tuen Mun Area 2A projects.

Finally the Government's Letter of Intent in respect of Tsang Tsui lagoons would require modification to facilitate the stocking and subsequent recovery of PFA to and from the lagoons in a flexible manner, utilising road, barge and dredging facilities as well as the existing pipeline.



Note:
1. See Section 2.3 for estimated quantities of PFA
2. Fill Requirements after 2003 are unknown

Figure 3.2(a)

Estimated Annual Fill Requirement and Territory Wide PFA Production

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

3.3 *DISPOSAL OF PFA*

Disposal facilities will be required for PFA arisings from CPPS and the LTPS at Black Point which cannot be utilised elsewhere. Any disposal facilities must also afford back up capacity for all arisings if future utilisation schemes fail.

Disposal of large quantities of PFA at sea, in dedicated landfills or lagoons will inevitably result in some level of environmental impact, be it to the visual environment of Hong Kong or the sterilisation of the seabed or inland sites. Hence, it is desirable that the development of any new facilities proceed only when they are required and that efforts are maximised to use by-products beneficially elsewhere. (The latter is also favoured on economic grounds; it typically costs in excess of HK$100/te to dispose of PFA in dedicated facilities and this feeds through to electricity bills.)

3.3.1 *The Options*

Options for the disposal of PFA are well known from previous studies both world wide and specifically in Hong Kong, for both CLP and HEC.[(3),(10),(9),(47)]. The options can be broadly classified as below:

- *Marine Lagoons:*
  - Continued Use or Extension of Tsang Tsui Lagoons;
  - New Lagoons.
- *Landfills:*
  - Dedicated PFA Landfills;
  - Restoration of Quarries/Borrow Areas.
- *Disposal At Sea*
  - In Hong Kong Waters (at gazetted dumping grounds or unfilled marine sand borrow areas);
  - In International Waters.
- *Codisposal:*
  - with FBA;
  - with FGD By-Products.
- *Use of Underground Caverns at Yuen Long.*

The issue of LTPS by-product disposal has been the subject of a recent site search and engineering feasibility exercise by CLP.

(47) L.G. Mouchel & Partners, *"Offsite Disposal of Ash & Gypsum"*, for National Power, UK (1990).

Of the options above, the codisposal of PFA or FBA with gypsum can be discounted as the materials may subsequently be re-excavated for use and mixing would reduce the usefulness of the by-products. Generally it is preferable to dispose of byproducts separately. Provision for this can be either at a different location or within dedicated areas of a particular disposal site.

The situation with regards to the caverns at Yuen Long[48] is that whilst it might be an elegant solution to the problem it is considered that insufficient information is available about the size, layout interconnection and hydrology to properly evaluate them. Extensive site studies would be necessary to fully explore this option.

CLP's site search identified possible disposal sites for the remaining options (see *Figure 3.3(a)*) and assessed these on a preliminary basis in terms of, their engineering, environmental and economic feasibility. Major practical or regulatory constraints to the use of these sites were investigated and consultations made. In the following sections the technical and economic issues associated with each disposal option are summarised and the environmental implications of each discussed.

Photographs of the identified potential disposal facilities are shown in *Annex D*.

3.3.2 *Marine Lagoons*

Currently, the only CLP disposal facilities for PFA are the ash lagoons at Tsang Tsui which currently hold about 2Mte (approx. $2Mm^3$) of CPPS PFA. Approved capacity at the lagoons is 7.5Mte of PFA. The Government's Letter of Intent in respect of Tsang Tsui Lagoons restricts the deposition method to slurry placement in addition to specifying that the facility is for the disposal of PFA only.

The site search identified four potential further marine lagoon sites close to Black Point (*Figure 3.3(a) and Annex D*); two to the north east of Tsang Tsui, within the mariculture zone, and two that comprise the proposed Tuen Mun Port Development reclamation area for cargo working areas and deep waterfront industry.

The working lifespan of these potential facilities vary according to development scenario, growth in electricity demand and PFA utilisation achieved, but would vary between 5 and 15 years beyond the time Tsang Tsui lagoons are full.

Each of these lagoons sites has been determined to be feasible on engineering grounds and preliminary designs completed. Each is discussed below in terms of capacity, lifespan, constraints to use and economic and environmental issues.

(a) *Tsang Tsui Ash Lagoons*

Tsang Tsui lagoons have been operating for about five years and were originally designed to receive the entire output of PFA from CPPS.

(48) GCO Report 2/90, *"Foundation Properties of Marble and Other Rocks in Yuen Long – Tuen Mun Area"*, (1990).

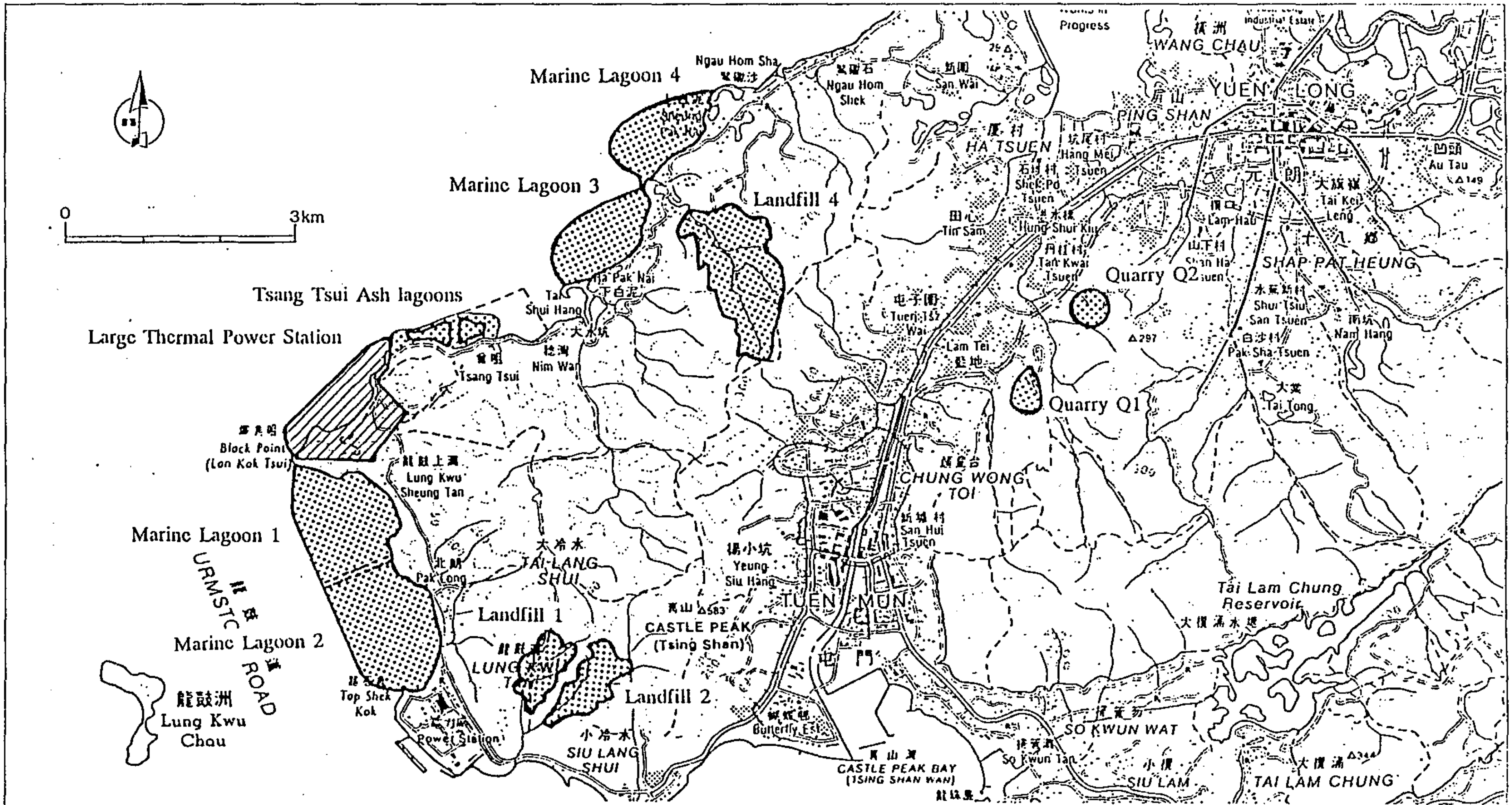


Figure 3.3(a)

Potential Disposal Sites

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

(i) *Capacity and Lifespan*

Tsang Tsui was envisaged as reaching capacity as early as 1996 with 10 years output from CPPS alone[9] (high growth in electricity demand and low utilisation of PFA). However, due to PFA utilisation, currently at 340 kte/yr the lagoons hold only about a quarter of their capacity at about 2 Mte of an approved capacity of 7.5Mte.

Planning for a situation incorporating an average growth in electricity demand (see *Section 2*), projections can be made as to the lifespan of the lagoons under existing licence conditions, but including the output from the LTPS under *Scenarios I* and *II.* (*Table 3.3(a)*).

Table 3.3(a)
Lifespan of Tsang Tsui Ash Lagoons

LTPS Development Scenario	**Utilisation Achieved**	**Estimated Lifespan (until)**	**Planning for New Facility**
I/II	None	1996	1993
I	Current - 340 kte/yr	1998	1995
II	Current 340 kte/yr	1999	1996

Note: Projections assume average growth in electricity demand and 16% ash content in coal - currently 11% average ash content coal is burnt.

Detailed planning and construction lead time for a new disposal facility has been estimated at 3 years from the time of site designation. If Tsang Tsui where to be utilised in the meantime for both LTPS and CPPS production, site selection would need to be complete three years before dates shown above. However, as discussed in *Section 3.2* utilization proposals already in place are likely to increase, rather than decrease utilisation, so the dates above must be regarded as conservative.

Proposals have been made to extend the ash lagoons by increasing the height to which the PFA can be stacked, and enlarging the site to take up the adjacent valley (*Figure 3.3(b)*). *Table 3.3(b)* shows likely lifespans with average growth and current utilisation rates.

Table 3.3(b) Lifespan of Extended Tsang Tsui Ash Lagoons			
LTPS Development Scenario	**Utilisation Achieved**	**Estimated Lifespan (until)**	**Planning for New Facility**
I/II	None	2005	2002
I	Current - 340 kte/yr	2008	2005
II	Current 340 kte/yr	2009	2006
Note:	Projections assume average growth in electricity demand and 16% ash content in coal - currently 11% average ash content coal is burnt.		

If the BBC Station is relocated elsewhere in 1997, the restriction of the radio waves on the height of the lagoons would be removed. The lagoons can be raised up to higher levels and extended inland. The proposed profile for the extended Tsang Tsui lagoons is shown in the attached sketch. It is estimated that the extended lagoons have a total capacity of 20.5 million cubic metres i.e. 13 million cubic metres greater than the current proposed envelope for which approval has been given.

Upper level bunds could be constructed using existing settled PFA/imported FBA (as drainage core) with material being lagooned up to a height governed by the hydraulic characteristics of the existing pipeline (probably about +30 to +35mPD). Thereafter placement from truck in conditioned form would be used.

(ii) *Constraints*

There are no constraints to the continued use of the lagoons for disposal of CPPS PFA within the current licence conditions.

Combined disposal of both LTPS and CPPS PFA would require Government approval and updating of the Letter of Intent (which would also require a provision for LTPS ash to be trucked to the site (see below)).

Extension of the capacity of the existing lagoons would require the closure or relocation of the BBC's radio station, either to higher ground or to an alternative vicinity. Further, under the on going Tuen Mun Port Development Study, the Tsang Tsui lagoon area is proposed for industrial/port development by 2011. Hence, any extension to the lagoon life or raising levels of PFA stacking would jeopardise any later development. If industrial development were to proceed an alternative disposal facility would be required for the stockpiled PFA.

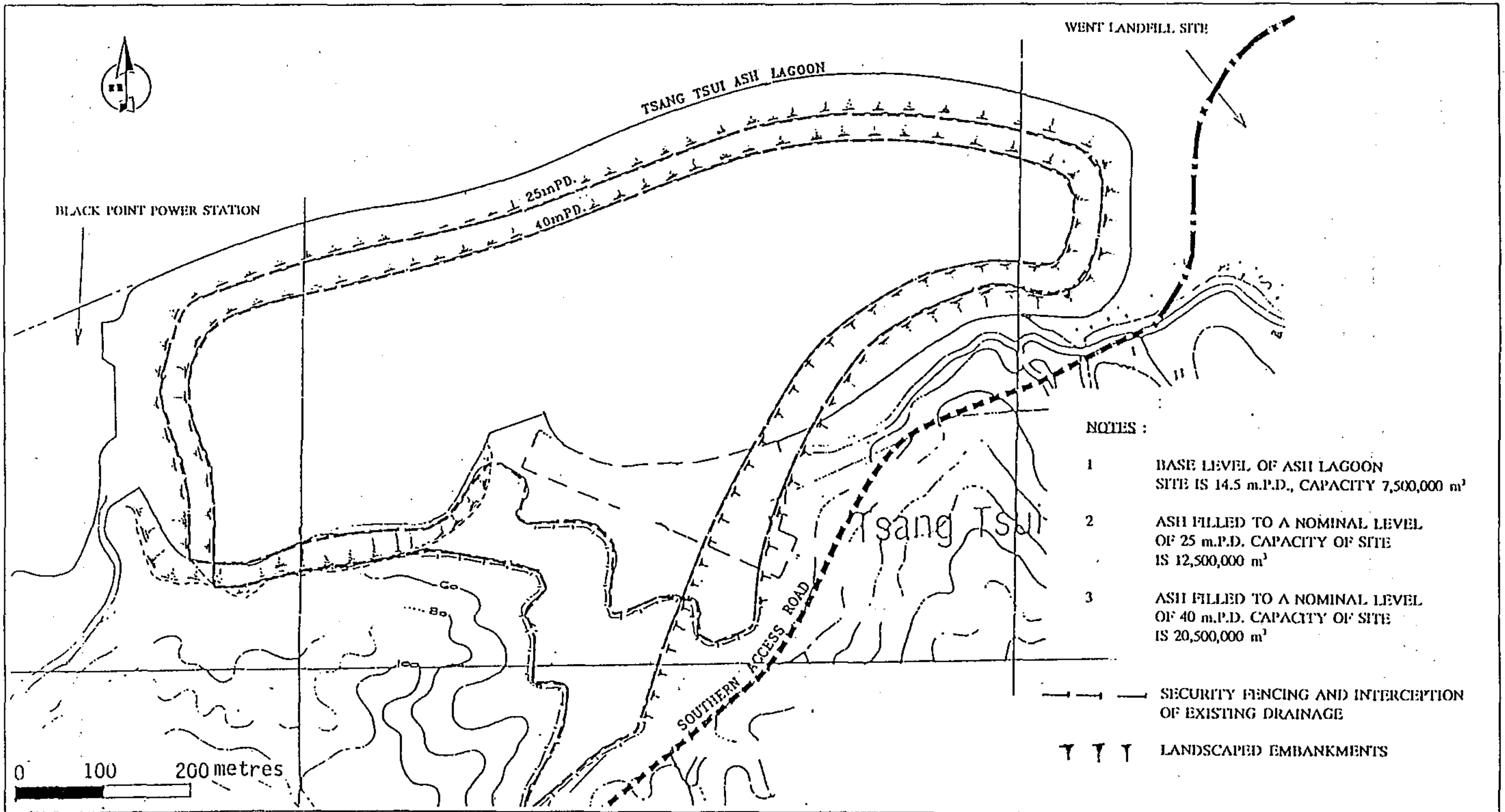


Figure 3.3(b) –

POTENTIAL FOR FURTHER EXTENSION OF TSANG TSUI SITE

ERM Hong Kong
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

(iii) Economic Issues

The estimated costs of disposing LTPS and CPPS ash at Tsang Tsui would be low compared to development of new facilities. Costs per tonne would be about a factor of 2 to 5 less than that for developing new facilities without accounting for land acquisition costs. Incorporating the latter could increase the factors to between 5 and 30 times.

(iv) Environmental Issues

Performance of the lagoons to date, in terms of environmental quality has not resulted in any significant impacts to the local environment in respect of air quality, noise disturbance and water quality. CLP have carried out extensive monitoring programmes at Tsang Tsui, as discussed in *Section 3.2.9*, and no adverse effect has been attributed to the lagoons in respect of raised levels of heavy metals in the waters adjacent to the lagoons (described in *Section 2*) Ambient levels of suspended solids in either air or water have not been cited as problems.

Trucking of PFA to the lagoons is currently only allowed as an emergency measure (during pipeline failure) for CPPS PFA. If trucking where to be used at Black Point, measures such as ash conditioning, use of covered trucks or tankers etc. would need to be instituted so that it could be adequately demonstrated that dust nuisance would not occur.

Extension of the capacity of the existing lagoons could potentially give rise to levels of environmental impact not envisaged in the original environmental assessment[9], in particular in respect of visual impact, air quality and noise. Raising the levels of placement significantly above those envisaged would certainly change the visual aspect of the area, but hydroseeding and restoration of the visible slopes as placement proceeds (as practiced at municipal landfills) would mitigate the effect in an area that would already be subject to the visual intrusions of the LTPS itself and the WENT landfill. It is understood that villagers in the area are likely to be relocated as part of the WENT or TMP developments and hence small increases in levels of environmental impact that may occur would affect many fewer receptors. Continuation and institution of appropriate site management practices as detailed in *Section 3.2,* should minimise any additional impact to acceptable levels.

(v) Recommendations

Continued use of the lagoons at Tsang Tsui for PFA from both CPPS and the LTPS is recommended. The lifespans indicated above, together with possible increases in PFA utilisation as set out in *Section 3.2* could put off the time when alternative disposal facilities are required by some considerable time. This would delay the construction of other facilities, in addition to allowing time for the development of ash markets and to plan for later disposal in detail. Hence, the environmental impact that would inevitably be incurred from new facilities, by the sterilisation of a large areas of Hong Kong's hillsides or shoreline would be delayed.

Extension of Tsang Tsui lagoons would realise further benefits in the delay or elimination of the need for alternative PFA disposal facilities. The two constraints to extension; relocation of the BBC relay station and possible deferment or cancellation of proposed PADS development (for which no firm demand is yet in place); would need to be overcome by CLP and Government.

It should be noted that despite indications in *Table 3.3(a)*, that planning and construction of any extension would be necessary before 1997. This is not very likely given the various proposals under consideration by CLP for use of the existing 2Mm^3 of PFA currently stored at Tsang Tsui (see *Section 3.2*). Hence, relocation of the relay station before 1997 is unlikely to be necessary.

(b) *Marine Lagoons ML1 and ML2*

(i) *Capacity and Lifespan*

ML1 and ML2 comprise a proposed reclamation for deep waterfront industry and/or cargo working area for the Tuen Mun Port (TMP) development under the PADS proposals. If utilised as dedicated PFA disposal facilities estimated capacity is 9 Mm^3 for ML1 and 8 Mm^3 for ML2. The working life of either lagoon could comprise between a minimum of 8 years from 1998 (*Scenario I*) and up to 8 years beyond 1999 (*Scenario II*) (These timings begin when Tsang Tsui would be full to current capacity given continuation of current utilisation rate – other conditions as per *Table 3.3(a)*).

The advantages of using these lagoons stem from their proximity to CLP's TPSs, lying between CPPS and Black Point.

(ii) *Constraints*

The major constraint to the use of these lagoons is the area's proposed use in the TMP development. The ongoing TMP Development Study[(49)] indicates that the first industries would require land as early as 1996. The entire reclamation would be occupied by 2006. Consolidation time would mean reclamation would need to be complete two years before the dates given above. Given that 3 years are likely to be necessary to plan and construct any disposal facility, there appears to be little scope for siting dedicated lagoon facilities in this area unless the TMP development were to be cancelled or delayed by a decade or more.

However, there would appear to be scope to utilise significant quantities of PFA in the reclamation. The TMP Development Study has indicated that over 3 Mm^3 of PFA could be utilised in above waterlevel sections of any reclamation prior to 2004 with considerable economic benefit to the project[(29)]. A further 0.15 Mm^3 is to be used above and below waterlevel to reclaim a staging area for the NWNT Sewer in the north of the reclamation area as discussed in *Section 3.2.9*. Successful completion of this project could further increase demand for PFA in the TMP reclamation's underwater sections.

(49) Scott Wilson Kirkpatrick et al *"Tuen Mun Port Development Study, Working Paper No.5, Industrial Demand Studies"* for Territory Development Department, Tuen Mun Development Office (1991).

(iii) *Economics*

If ML1 and ML2 were to be used as dedicated PFA lagoons, costs would be significantly higher than other disposal facilities and at least twice that of land based facilities, excluding any land acquisition costs. With land acquisition, costs could rise to four times that of land based facilities.

Conversely the cost of PFA for use as a reclamation fill in TMP reclamation is estimated at less than one third of the cost of alternative soft fills as discussed in *Section 3.2.9(a)(iv).*

(iv) *Environmental Issues*

Experience at Tsang Tsui has demonstrated that marine lagoons dedicated to PFA disposal can be operated without significant long term environmental impact. ML1 and ML2 are in an area less environmentally sensitive in terms of the marine environment. However, settlements at Lung Kwu Tan and Lung Kwu Sheung Tan would be subject to significant impact in terms of loss of amenity and visual intrusion. Further, in the immediate area of the lagoons it is likely that some periodic deterioration in air quality and noise environment would occur. Hence, the Consultants would recommend relocation of villagers if development were to proceed.

Slurry placed PFA will however cause far less visual, dust and traffic impact than the alternative fill sources and use of PFA should therefore be maximised. Early instigation of the project could also permit the emptying of the Tsang Tsui lagoons and the consequential supply of about 3 Mm^3 before 1996. This would conform very well with the concept of phased implementation of the TMP project.

The environmental concerns associated with the use of PFA in reclamations were reviewed in *Section 3.2.9(b).* As part of the TMP Development it is possible that villagers in Lung Kwu Sheung Tan will be relocated, whilst the situation at Lung Kwu Tan is as yet undecided. Study to date[(45),(50)] has not identified any overriding environmental impacts associated with PFA usage. It is not considered necessary to conduct further trials on PFA leaching in view of the extensive data already available, or shortly to be provided from on-going trials in the area.

(v) *Recommendations*

In view of the constraints posed by the upcoming TMP Development it is not considered viable to develop ML1 or ML2 as dedicated PFA lagoons unless, and until, the TMP Development is curtailed or postponed by a considerable time.

Maximisation of the use of PFA as a reclamation fill in the area is encouraged. The above water level requirement indicated by TMP Development Study preliminary reports[(45)] would utilise much of the excess output (over that currently utilised) from CPPS and hence extend the operating life of Tsang Tsui.

(50) Scott Wilson Kirkpatrick *et. al. "Tuen Mun Port Development Study, Working Paper No.8, Initial Environmental Assessment"* for Territory Development Department, Tuen Mun Development Office.

Subject to final approval of the use of PFA as an underwater fill. There might be scope for the development of a smaller lagoon in an area of the TMP reclamation not required until 2006, perhaps with a capacity of 4 to 5 Mte. This lagoon could be filled hydraulically with slurred PFA or by truck with conditioned ash and could be phased in with the TMP Development. Economics of this operation might be favourable if costs of seawalls were borne between the various benefiting institutions.

(c) *Marine Lagoons ML3 and ML4*

(i) *Capacity and Lifespans*

These two potential lagoon sites identified to the northeast of Tsang Tsui are both within the Deep Bay Mariculture Zone about 5 and 8.5 km from the LTPS and CPPS sites respectively. Capacity of each lagoon has been estimated at 5 Mm^3 giving lifespans of between 5 years from 1998 (*Scenario I*) and about 6 years from 1999 (*Scenario II*) after Tsang Tsui reaches capacity (*Table 3.3(a)* details calculation assumptions assuming utilisation continues at current rates).

(ii) *Constraints*

Practical constraints to the use of these sites centre on their location within the mariculture zone where foreshore developments are currently not permitted (see *(iv)* below).

(iii) *Economics*

The cost of using either of these potential lagoons is expensive. Excluding land acquisition cost it has been estimated that cost per tonne of PFA disposed would be twice that at land based facilities. This could rise to over five times that at land based facilities if land acquisition and compensation costs are added.

(iv) *Environmental Issues*

There are a number of strong environmental concerns associated with the use of these sites that do not favour their development:

- *Mariculture Zone:* The ML3 and ML4 sites are currently used for mariculture. Impacts to the marine ecology of the area is likely. Inner Deep Bay hosts a number of estuarine and coastal ecosystems, home to a variety of lifeforms found in few other parts of Hong Kong waters.

- *Water Quality:* The water quality within the area is important to the mariculture. The effect of any leachates that contain trace amounts of toxic metals would be heightened over those arising at Tsang Tsui.

- *Visual Impact:* Villages at Ha Pak Nai and Sheung Pak Nai are within the visual envelope of the ML3 and ML4 sites as is the Shekou Peninsula. Villagers would also suffer lost of amenity.

- *Air quality:* Periodic deterioration of air quality adjacent to the lagoons in respect of suspended particulates is likely, particularly during the dry season.. Villages and cultivated areas close to the lagoons could be affected.

(v) *Recommendation*

In the light of regulatory constraints, the vicinity of the mariculture zone, economic considerations and the sensitivity of the local environment, the development of either ML3 and ML4 is not recommended.

3.3.3 *PFA Landfills*

The site search for land based disposal facilities was limited to an area within about 10 km of the LTPS site due to economic and environmental considerations associated with transport. Note over 700 return vehicle movements could be required by 2016 if all solid by-products were landfilled.

The site search identified three feasible sites suitable for use as dedicated PFA landfills, shown on *Figure 3.3(a)* and in *Annex D* marked LF1, LF2 and LF4. Lifespans for these facilities range from about 8 years to well in excess of 30 years depending on firing scenario at the LTPS and utilisation rates. If developed, one or more of these sites could accommodate all PFA arisings from the proposed LTPS and CPPS.

The principal constraint to the use of either of these facilities is their location. All are within the Castle Peak Firing Range, administered by the British Military Forces. Consultations indicate that the Military would be unwilling to offer any site prior to 1997. The situation after 1997 remains uncertain since it is not yet known if the PRC Military would take over the site. The Consultants are aware that the FMC has conducted site investigations within the firing range to identify potential borrow areas for the WENT Landfill and for potential rock fill for PADs developments that would proceed prior to 1997.

On-going negotiations with the PRC are looking at the future of military establishments after 1997 and Government would be able to discuss the issue of a change in landuse or a reduction in the size of the firing range. This course is favourable on economic and environmental grounds to the use of potential sites further inland or sited on islands (where land is more heavily populated, designated as country park or transport of PFA would need to pass through population centres).

Past experience of landfilling PFA at Siu Lang Shui and land formation elsewhere in Hong Kong has shown that it can be accomplished without unacceptable impact to the local environment and that completed landfills can be restored for later reuse, provided an appropriate site is selected and designed with consideration for the environment[(22),(37)]. See also *Section 3.2.7(b)* where the environmental concerns of placing PFA on land are discussed.

The following sections briefly discuss the three identified landfills in terms of their local context in respect of capacity, lifespan, constraints, other than the Firing Range issue, economics and environment.

(a) *Landfill Sites LF1 and LF2*

(i) *Capacity and Lifespan*

Landfill sites LF1 and LF2 (*Figure 3.3(a)*) lie within 1 km of CPPS, directly to the north. The distance to the LTPS site is about 6 km. Both are valley sites with elevations between +30mPD to +230mPD. Ultimate capacities have been estimated at 10 Mm^3 for LF1 and 16 Mm^3 for LF2.

The combined lifespan of LF1 and LF2 is about 20 years under *Scenario I* firing from when Tsang Tsui is full in 1998 (assumptions as *Table 3.3(a)*). Under *Scenario II* this lifetime would be further increased. Hence, it is virtually assured that all PFA arisings from the LTPS could be accommodated from the first 20 years of LTPS operation (ever under a high electricity demand growth situation). Given some growth in PFA utilisation these two adjacent facilities could operate as long as the LTPS coal-fired units.

Towards the end of the study period, the Consultants have become aware of a proposal by PAA (Port and Airport Authority) to potentially extract rockfill for PADS developments from a large area of the firing range encompassing LF1 and LF2.

If the proposal went ahead then several million m^3 of rockfill would be removed prior to 1997. There are thus potential advantages to any later utilisation of this area for by-product disposal by CLP. The capacity of the landfills would markedly increase and the disposal operations could be used to progressively restore the proposed PAA Castle Peak Borrow Area. Further, the economics of disposal operations would benefit since existing facilities (access roads etc) could be used and topsoil would already have been removed simplifying site formation.

(ii) *Constraints*

Excepting the location of LF1 and LF2 within the Castle Peak Firing Range no other major practical constraints to their development have been identified.

(iii) *Economics*

Costs for PFA disposed at LF1 or LF2 are estimated to be moderate in comparison to other disposal facilities. (Costs do not include those associated with any water treatment facilities.) The costs would be considerably less than those for marine lagoons, except for the extended use of Tsang Tsui Ash Lagoons.

As noted above, the cost differentials may benefit if the PAA proposal where to go ahead.

(iv) *Environmental Issues*

Specific environmental concerns at the sites include ecology, visual impacts, valley streams, water quality, and noise from transportation and compaction:

- *Ecology:* LF1 and LF2 both contain high densities of vegetation and trees in the lower parts of their valleys. No detailed examination of flora and fauna is known to have been conducted, but in view of surveys conducted nearby, it is not considered that there is a high probability of the sites being of special scientific interest, however detailed examination would be required during the detailed planning for any facility. Development of the sites as a borrow area would, however have removed vegetation before PFA filling began.

- *Visual:* LF1 and LF2 sites are largely screened from potential receptors due to the restored municipal landfill at Siu Lang Shui between the sites and Lung Mun Road.

- *Streams:* Both LF1 and LF2 contain valley streams. These are not used for irrigation, nor do they form part of the catchment area for reservoirs or any other use. Reduction in flow due to reductions in catchment area resulting from landfill construction will not therefore have great impact.

- *Water Quality:* Leachate from landfill sites is of environmental concern and proposals for the three new municipal landfills indicate that containment and treatment will be required for new landfill developments to levels specified in the *Technical Memorandum on Effluent Standards* although runoff from landfills is currently excluded from the memorandum. Leachate characteristics of PFA are well known from several studies in Hong Kong.

  Leachate tests conducted as part of the SENT Landfill study[8] indicate that the critical contaminants in respect of PFA in the context of the TM are the cadmium and 'other toxic metals' criteria (see *Section 2.3)*. Requirements for containment at the landfills would need to be determined as part of the planning process since there is little hydrogeological data available. Treatment of runoff would also need to be assessed at this stage. However, landfill designs incorporating collection ponds and recycle water sprays would enable zero discharge to be maintained for much of the year and also aid dust suppression. In any event leaching could be controlled by ensuring good compaction of the PFA, by covering the surface of the disposal site with a sloping, well drained, geologically stable layer of low permeability capping material such as a PFA/Bentonite mixture (see *Section 3.2.7*), and by ensuring no groundwater can flow into the disposal site. Studies have shown that 400mm of rainfall are need to exact any leachate from a 1m bed of PFA[10] and that control as above could reduce leachate production to less than 50mm/yr at an annual rainfall of 700mm (c.f. 600mm at the WENT site nearby[51]).

(51) Hjelmar, Ole *"Leachate from Land Disposal of Coal Fly Ash"* Waste Management & Research 8, pp 429–449 (1990).

Further, the quantity of trace metals discharged in the locality is likely to render any resulting contribution from the landfill insignificant (NWNT Sewer, CPPS, TMP Development, Area 38 etc).

- *Noise:* The volume of traffic generated by-product disposal will be low when compared to that generated from the WENT facility, the LTPS and other planned developments. Operational noise would be emanating from an area far from population and hence its impact would be minimal.

(v) *Recommendation*

In terms of lifespan, capacity, engineering feasibility, economic and environmental issues the proposed landfills LF1 and LF2 are recommended for detailed study. LF1 and LF2 are recommended ahead of other landfills, new marine lagoons and quarry sites based on the above criteria.

(b) *Landfill Site LF4*

(i) *Capacity and Lifespan*

Located to the north east of Ha Pak Nai within the Castle Peak Firing Range (*Figure 3.3(a)*) about 6.5 km from the LTPS, landfill site LF4 has a very large potential capacity, broadly similar to that of the WENT municipal landfill. The site search exercise estimated the ultimate capacity at 55 Mm^3 and preliminary designs envisage a three phase development of the facility.

Assuming the very worst case PFA arisings (high ash content coal, high growth in electricity demand, 8 coal-fired units at the LTPS and no utilisation of PFA) LF4 could accommodate all PFA arisings up to 2016 (about 43 Mm^3) and beyond.

Phasing is envisaged in areas with volumes of 12 Mm^3, 21 Mm^3 and 22 Mm^3.

(ii) *Constraints*

LF4 is within the Firing Range and is used as a target practice area.

(iii) *Economics*

For Phase I of the LF4 facility it has been estimated that cost per tonne of PFA disposal would be moderate in comparison with alternative disposal facilities.

(iv) *Environmental*

Site characteristics of LF4 are broadly similar to those at LF1 and LF2, but in the valley below the landfill site are cultivated areas comprising fish farming, wildfowl breeding and agriculture. The villages of Ha Pak Nai and Sheung Pak Nai are nearby. Potential for environmental impact is therefore greater than above specifically:

- *Visual:* Operations at LF4 would be visible to some nearby villagers and workers in the ponds below the site. Its valley location would largely screen the facility from other nearby developments and the topography of the area would severely restrict views from Deep Bay.

- *Streams:* The streams from the LF4 catchment area are utilised by villagers downstream. Any significant reduction in flows to this may threaten livelihoods of local residents if alternative supplies were not made available. Conceptual designs indicate reprovisioning of water by diversion of the stream around the landfill area in surface water cut–off channels. Once areas of the site were restored, run–off water would be collected and discharged to the diverted stream. Adequate demonstration would be needed to ensure PFA would not enter the stream via surface or airborne routes.

- *Water Quality:* Similar concerns over run–off from unrestored areas in the landfill would arise as with LF1 and LF2 (see *(a)* above). However, discharge of this water untreated, to the existing stream is not advised if this is to continue to be utilised by villagers downstream, unless it could be demonstrated that significantly raised levels of trace metals and suspended solids would not arise.

- *Noise:* Economic considerations favour transportation by truck (in conditioned form) from CPPS and LTPS to LF4. The route would be via Nim Wan Road through Ha Pak Nai. Noise as well as traffic issues would need to be assessed in detail during planning studies to determine if upgrading or an alternate road would be required. The site is considered too distant from the villagers for noise impacts from onsite LF4 operation to be significant.

(v) *Recommendation*

This landfill site has a capacity capable of accommodating all by–product arisings from the two Power Stations for at least twenty years. The site is unlikely to be useable for any other purpose other than as a source of soft fill material. This use is in any event not inconsistent with the use of the site for PFA disposal.

Environmental issues render the site less attractive than LF1 and LF2 and detailed consideration would be required to ascertain whether impacts to villagers, fish farming and agriculture would be acceptable. In terms of long term strategy, CLP would suggest that the site be set aside for possible future use as a PFA landfill.

3.3.4 *Quarry Sites*

Two potential quarry sites were identified in close proximity to the LTPS site during the site search exercise. Disposal at disused quarry sites can afford certain environmental advantages in the gradual elimination of visual intrusion of open rock faces and restoration of original topography. Capping of the restored quarry with soft fill and hydroseeding aids the blending in of the site with surrounding landscape. Results can be effective as demonstrated at the Siu Lang Shui PFA landfill site near CPPS.

(a) *Location*

The identified quarries lie within 1 km of each other about 10 km due east of the LTPS site :

- Quarry Q1, the Lam Tei Quarry, lies immediately east of Lam Tei (*Figure 3.3(a)* and *Annex D*);
- Quarry Q2 is situated about 0.5 km to the northeast at Tan Kwai.

(b) *Capacity and Lifespan*

Capacity of the quarry sites will roughly comprise the same volume as material removed. This yields the capacities and approximate lifespans indicated in *Table 3.3(c)*.

Table 3.3(c)
Quarry sites capacities and PFA lifespans

		Lifespan	
Quarry Site	**Capacity (Mm^3)**	***Scenario I*** (yrs from 1998)	***Scenario II*** (yrs from 1999)
Q1 Lam Tei	5	6	7
Q2 Tan Kwai	4	5	6

Note: Lifespans from given dates refer to those from when Tsang Tsui Lagoons are filled to current capacity assuming PFA utilisation remains unchanged, average growth in electricity demand and burning of 16% ash content coal.

(c) *Constraints*

Quarry Q1 at Lam Tei is currently still active, but its contract comes up for renewal in 1992. Administration is the responsibility of GEO and since the usual contract period is for 10 to 15 years, extension of the contract could eliminate consideration until beyond 2002. Given that time would be required for detailed planning and construction of any disposal facility it is unlikely this site could be available prior to 2005 if the licence were extended by the usual lifespan.

Quarry Q2 at Tan Kwai was fully worked out and the site is administered by DLO (District Lands Office). Currently, the site is utilised as a contractor depot for construction of the Yuen Long–Tuen Mun eastern corridor and Yuen Long West Link, which forms a limit on the potential site extent to the northwest.

(d) *Economics*

The cost per tonne for PFA at Q1 and Q2 quarries sites has been estimated to be comparable to costs of landfills but more expensive than continued use of Tsang Tsui. As with preceding disposal options the costs indicated do not include those associated with any water treatment that may be required.

(e) *Environmental Issues*

Operation of either quarry as a PFA disposal facility in accordance with the practice indicated for landfills and reclamations should not result in any significant environmental impacts in respect of air quality, water quality and noise. Visually, improvements should be realised as discussed above.

Transport of PFA to the sites would be by truck in conditioned form. The available route via Lung Mun Road and Castle Peak Road would however require passing the edge of Tuen Mun New town. Environmentally the impact of the increased traffic should not be excessive given currently predicted loadings.

(f) *Recommendation*

Utilisation of Quarry Q1 or Quarry Q2 would require action from GEO or DLO respectively as regards availability. In view of the comparable economic cost and low environmental impact indicated consideration of the sites is recommended. However, these sites may be preferred as possible gypsum disposal sites if the limestone/gypsum FGD system were selected (see *Section 5.3*).

Use of either Quarry, if coal firing were selected at the LTPS, would not afford much benefit since adequate backup capacity would still need to be found elsewhere unless utilisation showed marked improvement.

3.3.5 *Disposal at Sea*

In the past, countries such as the UK have practiced the marine dumping of PFA in the open sea. These actions have now ceased in most developed countries as the issue has become politicised and concerns have grown over effects to marine ecosystems through sterilisation of the seabed, leaching of heavy metals, disturbance to fish and issues associated with floaters (small glassy spheres that float on the surface). Sea dumping is also difficult to control to within a specified area.

Dumping of PFA into the sea is covered by two international conventions:

- *United Nations Convention on the Law of the Sea (UNCLOS) 1982:* This requires individual states to adopt laws and regulations to reduce and control pollution of the marine environment by dumping. These must ensure that dumping is not carried out without the permission of the competent authorities of member states and no dumping is permitted in a state's territorial waters, or onto the Continental Shelf without its express prior authorisation. National laws and regulations must not be less effective than the global rules and standards (Art.210).

- *Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Dumping Convention, LDC)*: This Convention, which entered into force in September 1975, governs dumping on a global basis. Contracting states are required to apply a licensing system to any waste dumped at sea from vessels or aircraft before authorisation is given authorities should give careful consideration to environmental effects. The convention prohibits the dumping, except in trace quantities, of certain substances deemed to be toxic, persistent and bioaccumulative, e.g. crude fuel and lubricating oils, radioactive waste and industrial wastes. Licenses to dump waste at sea must contain information of the quality and quantity of the wastes to be dumped, and may also specify the site and method of dumping. Fishery departments carry out spot checks on dumping operations to ensure that licensing conditions are being met; they also survey the major dumping grounds at intervals to determine the effects of waste disposal.

  In the context of UNCLOS, EPD is the competent authority and could authorise disposal of power station wastes at sea. PFA would not necessarily be considered a toxic waste under the LDC convention (enforced in Hong Kong via the *Dumping at Sea Act 1974 (Overseas Territories) Order 1975).*

In its Waste Disposal Plan for Hong Kong[21], EPD specifically address the issue of PFA disposal at sea.

> *"Disposal at sea is not a favoured option for three reasons. First, a proportion of PFA consists of vitrified, hollow spheres which will float and which may hence produce a problem of pollution of surficial water. Second, when deposited in bulk in seawater physico-chemical reactions lead to the formation of amorphous "concrete" lumps. If these were to accumulate on the sea bed they could present a navigational and fishing hazard. Third, PFA and FBA are relatively rich in concentrations of potentially toxic heavy metals. Deposit of these in a concentrated manner on the sea bed may pose a threat to marine life and, through possible concentration through the food chain, a threat to public health."*

Evidence on the effects of PFA marine dumping is sketchy. In the US, research indicates that build up in organisms of selenium (Se), arsenic (As), cadmium (Cd), and chromium (Cr) may occur.

The issues that would require resolution are:

- Is the build up of heavy metals due to dumping of PFA unacceptable? With the 3 Mte/yr envisaged in 2016 the total would be substantial.

- Does PFA lead to smothering of the sea bed? Evidence on basis of smaller rates of disposal suggests not. This however, relates to lower "application" rates. Would amorphous lumps form in sufficient size to constitute a hazard?

- Alternatively could a PFA concrete block "reef" (or PFA/Gypsum mixes) provide a better means of disposal? This would provide useful habitat creation/management potential and could help fish stocks.

The Agriculture and Fisheries Department are known to be planning an experimental artificial reef, which is envisaged as being made from PFA concrete blocks. The artificial reef issue is addressed more fully in *Section 5.2.5*.

The restricted availability of land based and marine lagoon disposal sites in Hong Kong merits consideration of the marine dumping options despite the above. There are three main alternatives for disposal of PFA at sea:

- Direct marine dumping at gazetted marine dumping areas in Hong Kong;

- Backfilling of redundant marine borrow areas in Hong Kong;

- Unconfined Marine Dumping in International Waters.

(a) *Gazetted Marine Dumping Areas*

During the next several years of the PADS development there will be a considerable pressure on the disposal capacity at the existing gazetted disposal areas, particularly South of Cheung Chau and East of Nine Pins. Much of the demand will be for marine muds. Recent Fill Management Committee estimates put the total amount of marine mud to be dredged up to and including the year 2000 at about 365 Mm^3, almost 300 Mm^3 of which will be dredged before 1996. These volumes do not include overburden dredged during the exploitation of borrow areas.

EPD estimate the present capacity of the three existing disposal areas as follows (late 1991):

- South of Cheung Chau: < 30 Mm^3
- East of Nine Pins: 28 Mm^3
- Mirs Bay: 9 Mm^3

The proposed western extension of South Cheung Chau is estimated to have a capacity of about 67 Mm^3 and the proposed eastern extension about 56 Mm^3. It is unlikely that the eastern extension will be adopted however, due to Marine Department concerns. This being the case, it appears that the capacity of the gazetted borrow areas is no more than 134 Mm^3.

In view of the substantial demand for offshore disposal capacity over the next few years, it is most unlikely that the large quantities of PFA arising from the LTPS Development can be accommodated in the existing disposal areas.

(b) *Redundant Marine Borrow Areas*

At present, there is only one area where redundant borrow pits can be used as a disposal facility. The pits, used by the contractor for the Tin Shui Wai Land Formation contract, are situated just off Black Point in Urmston Road. They have a capacity of approximately 20 Mm^3 and have recently been designated for the disposal of contaminated sediments. Considerable amounts of these sediments are expected to arise in the forthcoming years.

Additional disposal capacity will arise in the future in borrow areas which are worked for other PADS projects and for some private developments such as Container Terminals 8 and 9. It is expected that contractors on these projects will attempt to maximise the internal disposal capacity of these areas by employing a strip mining method and dividing the areas into a number of pits which are worked and then backfilled sequentially. It is inevitable, however, that some areas will not be completely backfilled and that some capacity will be available for other projects.

Not all borrow areas will be suitable for backfilling. Areas such as Kap Shui Mun and West Sokos are not suitable because of their active hydrodynamic character.

At this stage, it is not possible to make confident predictions of which borrow areas would be available for disposal of PFA. FMC have indicated that any disposal capacity which remains in the areas worked for the New Airport would be made available for later PADS developments proceeding up to 2011.

(c) *Unconfined Marine Dumping*

Open sea disposal options include dumping in PRC waters and dumping in international waters. Neither of these options are available now but, subject to changes of local legislation and international agreement, might be possible in the future.

Dumping in PRC waters might be possible in the area of the Lema channel where water depths are typically of the order of 30m. The area lies within the oceanic current system. It is unlikely that any large quantities of dumped material would re-enter the Pearl Estuary from this location. The distance to the middle of the channel from the LTPS is approximately 50 km.

As far as the Consultants are aware, there is no formal definition of the extent of PRC waters. If a 12 mile limit is assumed, from Dangan Liedao, the transport distance to international waters is about 80 km from the LTPS site.

The continental shelf beyond the Pearl River Estuary lies over 150 km from Hong Kong. It has previously been proposed by others that the dumping of PFA at the continental shelf would alleviate many of the potential concerns expressed above since the ash would be carried to great depth with Pearl River silt.

In view of the distances and hence the costs involved, this option has not been pursued further, although environmentally speaking it would appear to represent the least significant unconfined marine dumping option.

(d) *Recommendation*

Of the options discussed above, it would appear that only the unconfined marine dumping in international waters has scope as a PFA management strategy for at least the earlier years of LTPS development. Pressure on Hong Kong's limited sea dumping areas is very unlikely to facilitate the dumping of large quantities of PFA until well into the next century. Dumping at the Pearl River mouth would require the agreement of the Chinese authorities, whilst the distance to international waters is excessive. Either option would add extra traffic to Hong Kong's already congested shipping channels. Harvesting of dumped PFA for later reuse would not be possible.

The Consultants would maintain that dumping 3 Mte/yr via marine disposal of a potentially useful reclamation material is of dubious value. However, without adequate monitoring of similar scale operations (there are none) it is difficult to conclude that it would be environmentally damaging.

Such an operation would, however, go against the tenor and spirit of International Conventions on prevention of dumping at sea. This is despite the fact that it could still be sanctioned by the competent authority (i.e. EPD).

The Consultants would recommend that Sea Dumping of PFA, outside Hong Kong waters is only pursued when, and if, all other options are exhausted.

3.4 *INTEGRATED 20 YEAR MANAGEMENT STRATEGIES*

3.4.1 *Introduction*

Sections 3.2 and 3.3 have summarised the various options available for the beneficial utilisation and disposal of PFA respectively. In line with the objectives of the KIA (*Section 1.2.1*) feasible management options identified in the preceding sections are compiled below into long-term strategies incorporating current Hong Kong practice and legislation and the need for a secure disposal route under the most pessimistic conditions foreseeable. Further, those options determined to be suitable, but presently not practiced or that are not currently sanctioned by Government are considered where the environmental advantages were found to be significant.

Management options for PFA are considered here in isolation from those for other by-products.

3.4.2 *Beneficial Utilisation of PFA*

Table 3.4(a) summarises the major utilisation options found to be feasible in *Section 3.2*. Utilisation rates of those options with identifiable market potential are estimated under three different categorisations:

- *Present Utilisation* rates represent the existing rates of PFA use projected forward to 2016 and assuming no market growth.
- *Projected Utilisation* incorporates projects currently under discussion such as landfill uses, Tuen Mun Port Reclamation etc, plus anticipated growth in the concrete market based on existing trends and attitudes.
- *Potential Utilisation* projects consumption rates considered achievable with active support from Government by way of removal of existing restrictions on use, plus legislated changes making the use of ash in concrete and reclamations mandatory when available.

Figures 3.4(a) and *3.4(b)* show the effects of estimated continuous utilisation rates on the quantity of CPPS and LTPS PFA remaining under *Scenario I* and *II* firing configurations respectively. It should be noted these utilisation rates are based on pessimistic assumptions where there is doubt.

3.4.3 *Disposal of PFA*

Table 3.4(b) summarises the identified disposal sites that could be used to receive any PFA not beneficially utilised. From a technical and engineering view point all are feasible. However on timing, environmental and economic grounds development of new dedicated marine lagoon facilities within Deep Bay are not favoured.

Figures 3.4(a) and (b) show projected lifespans of the various options (assuming Tsang Tsui is first filled to existing capacity) given the different utilisation rates over 20 years for LTPS lifetime for *Scenario I* and *II* respectively.

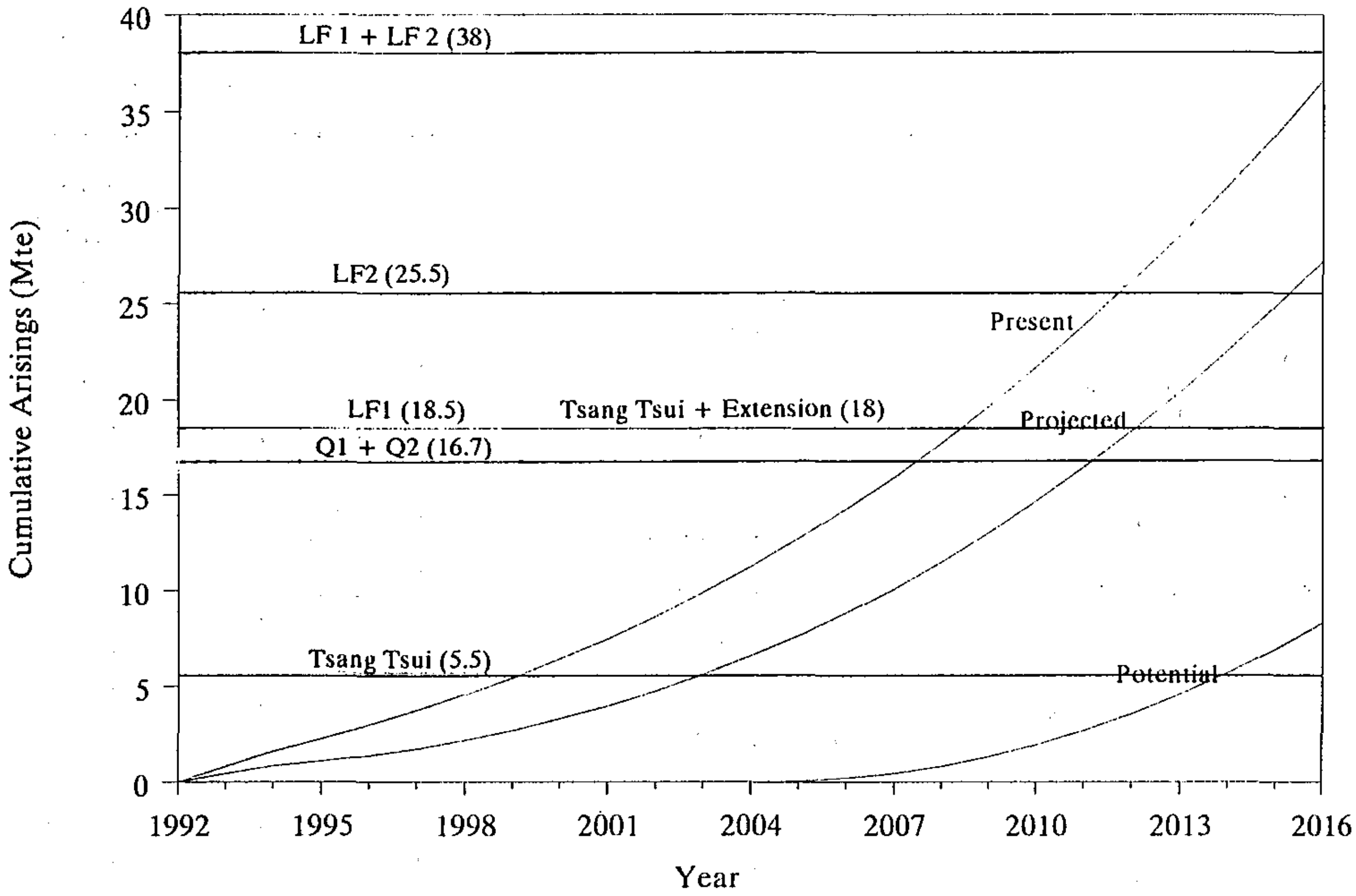
Table 3.4(a)
Likely and Potential Foreseeable PFA Utilisation From CLP TPSs

Utilisation Method	Present Utilisation		Projected Utilisation		Potential Utilisation		Remarks
	Rate Mte/yr	Cumulative Mte	Rate Mte/yr	Cumulative Mte	Rate Mte/yr	Cumulative Mte	
Cement Manufacture	0.16[1]	3.8	0.16	3.8	0.16	3.8	[1] Assumes continued operation of one kiln.
Concrete Production	0.08	1.9	0.2[1]	4.8	1.1[2]	26.4	[1] Assumes normal market growth [2] With Government legislation making use of PFA at 25% TCC mandatory.
Refuse Interleaving	Nil	Nil	0.27[1]	6.5	0.4[2]	9.6	[1] WENT use only [2] SENT & WENT use
Reclamation and Site Formation	0.1	2.4	0.1	5.0[1]	All Remaining Production[2]		[1] WENT, SENT & TMP. [2] With Government legislation making use of PFA in reclamations mandatory if available.
Totals	**0.34**	**8.1**	**0.73**	**21.1**	All Arising PFA		

Table 3.4(b)
Potential PFA Disposal Facilities Summary

Disposal Facility	Capacity		Lifespan[3]		Cost (Rank)[4]	Likely Environmental Acceptability[7]	Constraints to Development	Government Actions
	(Mte)	(Mm³)	Scenario I (yrs)	Scenario II (yrs)				
Tsang Tsui	5.5[1]	5.5	1998	1999	Very low (1)	Acceptable	-	-
Tsang Tsui Extended	13	13	2008	2009	Low (2)	Acceptable	a. BBC Radio Station Relocation b. TMP Development proposed for 2011	a. Alteration of Letter of Intent b. Deferment of proposed TMP Development
ML1 + ML2	17[1]	17	2010	2011	High (8) (Low[5])	Acceptable	a. TMP Development proposed 1996-2011	-
ML3 + ML4	10[1]	10	2006	2008	Very High (9)	Poor	a. Located in Mariculture Zone	-
LF1	12.5[2]	10	2007	2009	Moderate (7)	Acceptable	a. Located in Firing Range	a. Approval of Firing Range use
LF2	20[2]	16	2011	2013	Moderate (3)	Acceptable	a. Located in Firing Range	a. as above
LF4	68.7[2]	55	Beyond 2026	Beyond 2026	Moderate (6)[6]	Possible	a. Located in Firing Range b. Possible need to relocate villagers	a. as above
Q1	6.2[2]	5	2004	2005	Moderate (4=)	Acceptable	a. Quarry still active b. May be more suitable for alternative by-product	a. GEO limiting quarry licence from 1992
Q2	5[2]	4	2003	2004	Moderate (4=)	Acceptable	a. Currently contractors depot b. May be more suitable for alternative by-product	a. DLO to approve change of use

1 Assumes settled density of 1 te/m³
2 Assumes compacted density of 1.25 te/m³
3 Assumes average growth in electricity demand, 16% coal ash content, minimum foreseeable utilisation at 0.34 Mte/yr. Lifespans given assuming prior Tsang Tsui completion under current licence conditions.
4 Given as broad estimates of relative costs, ranks in order of ascending cost per tonne, including land acquisition, construction and operation. An incremental cost is given for Tsang Tsui.
5 Based on use as soft fill into reclamations constructed by others.
6 Based on Phase I only. Subsequent phases would be less expensive.
7 Given institution of recommended mitigation measures and satisfactory completion of a detailed EIA

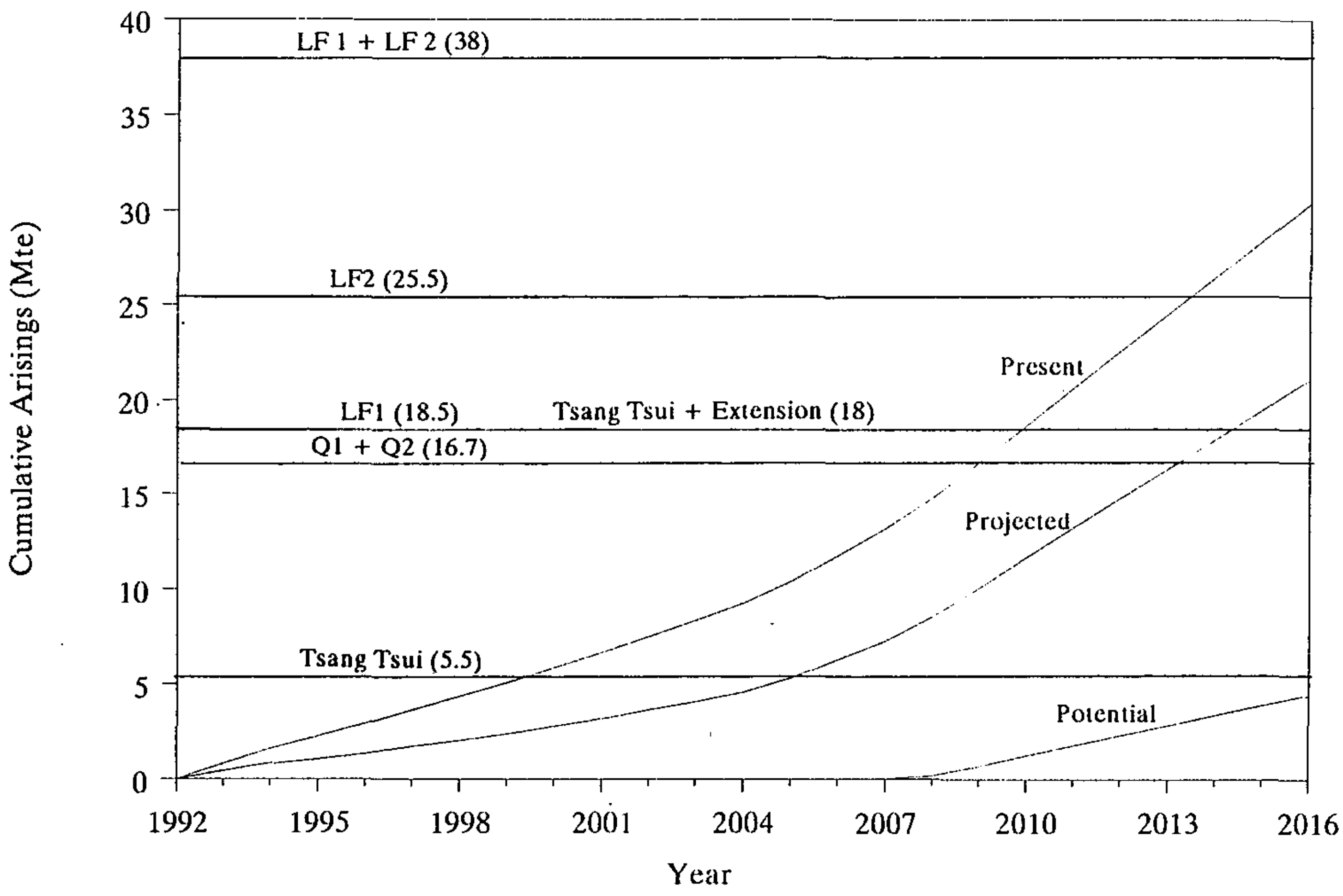


Note: Alternative disposal site capacities assume Tsang Tsui is first filled to capacity.

Figure 3.4a – Comparison of Landfill and Quarry Site Lifespans for PFA Disposal – SCENARIO I

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong



Note: Alternative disposal site capacities assume Tsang Tsui is first filled to capacity.

Figure 3.4b – Comparison of Landfill and Quarry Site Lifespans for PFA Disposal – SCENARIO II

ERM Hong Kong
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

The available disposal sites were initially ranked assuming all produced PFA would require disposal based on five criteria:

- Constraints to planned development and availability
- Capacity
- Distance from LTPS and CPPS TPSs
- Environmental acceptability
- Relative cost per tonne disposed

Feasible sites were ranked in the following order:

1 Continued use of Tsang Tsui;
2 Extended use of Tsang Tsui;
3 Landfills;
   a) LF2;
   b) LF1;
   c) LF4;
4 Quarries;
   a) Q1;
   b) Q2 (dependent on requirement for gypsum/FBA disposal)

This ranking is weighted fairly heavily towards capacity and hence some alteration can be expected depending on the utilisation rate achieved and thus capacity of disposal site required. For example if utilisation rates are high, the lower capacity quarry sites become more favourable due to the environmental benefits afforded by site restoration.

This ranking also ignores the use of ash in the Tuen Mun Port Reclamations (ML1/2) which although it is the cheapest and most environmentally benign 'disposal' option is considered under beneficial utilisation.

Management strategies incorporating disposal facilities are dependent on the ultimate amount of backup disposal capacity required, which will vary according to utilisation achieved. The latter will in turn depend on market factors and Government actions.

Assuming utilisation does not increase over current levels (340 kte/yr) detailed planning for a new disposal facility would not be required before 1995 (*Scenario I*) or 1996 (*Scenario II*) at the earliest (allowing three years lead time). By this time it will be clearer what the utilisation rate in the Territory will be and PFAs increased use in the major markets identified will either have begun or it can be assumed they will not materialise in the foreseeable future (e.g. concrete, interleaving material, AACBs, underwater sections of reclamations).

Hence, in the light of *Figures 3.4(a)* and *3.4(b)*, the ranking of disposal sites can be amended according to utilisation rate, disposal site capacity required and firing scenario.

(a) *Disposal facilities ranking – Scenario I*

Table 3.4(c) ranks identified feasible disposal facilities under three foreseeable utilisation rates on the basis of providing secure disposal capacity over the study period. It can been seen that the rate of growth in electricity demand is not an overriding factor in determining facility lifetimes. In ranking the sites consideration has been given to the capacity required at each utilisation rate, economic implications and environmental criteria. Use of any of the facilities identified requires the resolution of a least one constraint (see *Table 3.4(b)*). If the use of any particular facility is not feasible due to the constraints, its rank is forfeited. Planning considerations should then focus on the facility ranked below.

(i) *Tsang Tsui Ash Lagoons*

Regardless of utilisation rates the continued use and extension to the life of the lagoons is a favoured option since this puts off (maybe indefinitely) the time when a new disposal facility must be developed. The lagoons can also act as a storage facility of PFA not required by continuous users that could later be harvested for use in reclamation.

(ii) *Quarries and Landfills*

Designated PFA landfills are favoured over use of quarries at lower utilisation rates on capacity and economic considerations. The ranking order LF2, LF1 (or LF1 + LF2), LF4 generally holds. Given higher utilisation, capacity becomes less important and the environmental advantages of quarry restoration become more favourable particularly if development of any landfill can be avoided. This would only result if both quarries could be used in sequence for dedicated PFA disposal facilities, except with very high utilisation rates where one would suffice. Use of the quarry sites for disposal of other potential by-products is discussed in the following sections.

(b) *Disposal Facilities Ranking – Scenario II*

A similar ranking of potential disposal facilities for *Scenario II* firing was undertaken. *Table 3.4(d)* shows the results.

(i) *Tsang Tsui Ash Lagoons*

Continued use of these facilities is favoured more strongly than if 8 coal units are commissioned. Even without an extension to the site, it will be possible to continue operation for almost a decade and given optimistic growth in utilisation rate the existing lagoons could still be operating beyond 2016 and for the entire life of the LTPS if extended.

Table 3.4(c)
Ranking of Disposal Facilities under Various Utilisation Rates – Scenario I

Disposal Facility	Utilisation Rate (continuous)[1]					
	Present (340 kte/yr)		Projected (730 kte/yr)		Potential (1760 kte/yr))	
	Lifespan Range (until)[2]	Rank[3]	Lifespan Range (until)	Rank	Lifespan Range (until)	Rank
Tsang Tsui	1998–99	1	2001–03	1	2009–12	1
Extended Tsang Tsui	2007–09	2	2010–14	2	2019–Beyond 2026	2
LF2	2010–13	5	2012–14	6	2024–>26	4
LF1	2006–09	6	2009–14	7	2019–>26	7
LF1 + LF2	2014–19	3	2018–24	3	Beyond 2026	8
LF4	Beyond 2026	4	Beyond 2026	4	Beyond 2026	9
Q1	2003–05	8=	2006–10	8=	2015–24	5
Q2	2002–04	8=	2005–09	8=	2014–23	6
Q1 + Q2	2006–08	7	2009–13	5	2016–26	3
Planning Date	1995		1998		2007	

Notes:
1 Continuous utilisation rates as defined by *Table 3.4(a)* – lifespans do not include any raised levels of PFA use in reclamations.

2 Projected lifespans from Tsang Tsui Completion, Range given from low to high growth in electricity demand given 16% average ash content coal.

3 Rank based on study period 1992–2016, based on capacity, economic and environmental criteria. Constraints given in *Table 3.4(b)* require resolution.

Table 3.4(d)
Ranking of Disposal Facilities – Scenario II

Disposal Facility	Utilisation Rate (continuous)					
	Present (340 kte/yr)		Projected (730 kte/yr)		Potential (1760 kte/yr)	
	Lifespan Range (until)[1]	Rank	Lifespan Range (until)	Rank	Lifespan Range (until)	Rank
Tsang Tsui	1999–2000	1	2004–05	1	2016–21	1
Extended Tsang Tsui	2009–10	2	2013–15	2	Beyond 2026	2
LF2	2012–14	5	2017–20	3	Beyond 2026	4
LF1	2008–10	6	2013–15	5	Beyond 2026	5
LF1 + LF2	2019–21	3	2025–26	6	Beyond 2026	n.a.
LF4	Beyond 2026	4	Beyond 2026	7	Beyond 2026	6
Q1	2005–06	8=	2009–11	8=	Beyond 2026	3=
Q2	2004–05	8=	2008–10	8=	Beyond 2026	3=
Q1 + Q2	2008–09	7	2012–14	4	Beyond 2026	n.a.
Planning Date	1996		2001		2013	

Notes:

1 Continuous utilisation rates as defined by *Table 3.4(a)* – lifespans do not include any raised levels of PFA use in reclamations.

2 Projected lifespans from Tsang Tsui Completion, Range given from low to high growth in electricity demand given 16% average ash content coal.

3 Rank based on study period 1992–2016, based on capacity, economic and environmental criteria. Constraints given in *Table 3.4(b)* require resolution.

n.a. not applicable

(ii) *Quarries and Landfills*

The ranking is broadly similar to that for *Scenario I* particularly if utilisation does not rise significantly. The order of preference remains the same between landfills, but at higher utilisation rates use of the two quarries together is favoured over development of LF4 or LF1 since with only a relatively small rise in utilisation Q1 and Q2 could dispose of PFA for the entire study period. If utilisation remains low; then LF1 + LF2 are favoured, but if projected utilisation materialises the quarries become progressively more favourable. The timing requirement for a new facility would enable continued quarrying at Q1, further increasing its capacity.

3.4.4 *PFA 20 Years Management Strategy*

Overall strategy for the management of PFA is to maximise beneficial utilisation whilst minimising environmental and economic impact of disposal facilities within the study period from 1992 to 2016.

a) *Beneficial Utilisation of PFA*

As described in Section 3.4.2 the utilisation rate of PFA could vary between about 340 kte/yr, under the most pessimistic foreseeable market conditions, to the entire Territories output given optimistic market development and appropriate Government actions. Ongoing strategic actions are given below (*Table 3.4(e)*).

b) *Disposal Facilities*

Tables 3.4(c) and *3.4(d)* indicate the earliest date for detailed planning of any new disposal facility at 1995 for *Scenario I* and 1996 for *Scenario II*. By this time a secure site should be designated, necessary actions are summarised below (*Table 3.4(f)*).

Table 3.4(e)
PFA Utilisation Strategy Actions

China Light and Power Company	**Government**
Concrete & Cement	
• Continued aggressive marketing of PFA in Concrete & Cement and the provision of classification facilities	• Continued relaxation of restrictions on PFA use by Housing Department and BOO • Statutory minimum for PFA use in concrete at 15 or 25% of TCC.
Interleaving Material	
• Marketing/trials	• Require consideration of PFA by landfill tenderers and encouragement by Government for PFA use if trials successful.
Reclamation	
• Maintain low cost supply in marketing initiatives	• Encourage use of PFA by making use of PFA in reclamations mandatory subject to availability.
General	
• Continue investigations/marketing for new or novel markets	

Table 3.4(f)
PFA Options Strategy – Actions

China Light & Power Company	Government
Tsang Tsui	
• Investigate further the feasibility of extended lagoons and relocation of BBC radio station. Apply for altered licence.	• Investigate requirement by PADS for Tsang Tsui in 2011. • Permit Tsang Tsui extension, if feasible.
Landfills	
• Apply for provisional licence	• Determine if parts of the firing range could be decidicated as PFA landfills post 1997 and allocate site as future PFA landfills.
Quarries	
• Apply for provisional licence	• Determine availability of quarry sites.
Marine Dumping	
• Investigate dumping in PRC or international waters only if other disposal routes are determined unavailable	

4 *FURNACE BOTTOM ASH (FBA) MANAGEMENT*

4.1 *INTRODUCTION*

Furnace bottom ash is a granular by-product of coal combustion formed in the boiler by the fusion of ash particles. In Hong Kong about 1 tonne of FBA is produced for every 9 tonnes of PFA arisings. Its chemical content is broadly similar to PFA although its physical characteristics differ. Currently CLP produce about 350 te/day of FBA and all is sold commercially as an aggregate in the manufacture of lightweight concrete building blocks.

Under the high electricity demand forecast and *Scenario I* CLP would be producing a total of about 0.36 Mte/yr; a cumulative quantity of about 6 Mte by 2016. HEC could be producing about half this quantity at 0.17 Mte/yr, a cumulative quality of about 3 Mte by 2016.

In many parts of the world FBA is not disposed of, commercial demand for use in concrete blocks or as a drainage or sub-base material in road construction outstrips supply. At the time the IAR(3) was produced it was thought that similar conditions prevailed in Hong Kong. However, CLP have since indicated that there are doubts as to whether the market could absorb all the FBA likely to be produced. Hence, it is necessary that backup disposal facilities are available to receive any FBA not absorbed by existing or other potential markets.

The Governments' "*Waste Disposal Plan For Hong Kong*" specially addressed FBA and concluded (as for PFA) that commercial sale was favoured over disposal, but if not possible disposal should take the form of long term storage in lagoons, while its use for land restoration and reclamation should be investigated as a possible long term disposal option.

4.2 *BENEFICIAL USE OF FBA*

4.2.1 *The Options*

FBA has properties equivalent to those of a weak aggregate, but is less dense than conventional aggregate. It is potentially a valuable by-product and its properties make it appropriate for many of the same uses as PFA. However, utilisation in cement is not an option because of FBA's larger particle size and it is neither spherical nor 'glassy' like PFA. Similarly FBA has limited value as an aggregate replacement for use in structural concrete on strength grounds. Potential beneficial utilisation options identified for Hong Kong are as follows:

- Manufacture of lightweight concrete building blocks and tiles
- Aggregates Replacement as:
  - Sub-base material in road construction;
  - Free draining material in infrastructural projects;
  - Hardcore for temporary standing areas.
- Interleaving Material at municipal landfills

- Reclamation Material

As is the case with PFA, any utilisation strategy would benefit most from uses that have a significant continuous demand rather that large intermittent demand, since the former do not require stockpiling of the by-product.

4.2.2 *FBA in the Manufacture of Concrete Blocks*

Currently all CPPS FBA is sold to Kin Ching Besser Company for the manufacture of lightweight concrete blocks.

(a) *Economic and Technical Aspects*

Use of FBA in the manufacture of concrete blocks affords a number of technical benefits[23] in:

- higher strength and lightweight building material;
- improved casting operations;
- improved surface finish;
- reduced weight;
- low thermal conductivity.

Economically, Kin Ching Besser benefits from using FBA as an alternative to conventional aggregate.

(b) *Environmental Aspects*

Kin Ching Besser's plant is located relatively close to CPPS; near Area 38, behind Lung Mun Road and FBA, is trucked from the CPPS. Environmental impacts of the process are not known to be significant. (See also *Section 3.2.3(b)* where other environmental concerns of ash in building materials are addressed.)

The environmental benefits of these operations follow those described in *Section 3.2.2(b)* in the elimination of a potential waste product, and the elimination of the need to quarry alternative materials. Trucking would be required regardless of ultimate destination.

(c) *Market Potential*

In theory, the concrete block market in Hong Kong could absorb all FBA production. However, competition to Kin Ching Besser from K. Wah in Hong Kong (who do not use FBA) and increasingly from cheap imported blocks and red bricks from Guangdong, PRC, mean that they are finding it difficult to take all CLP's FBA during the peak production (of FBA) period in the summer. That K. Wah do not use FBA is largely a matter of the economics of ash transport. This situation could alter if a site close to FBA producers were available on a long term lease.

Current consumption by the block manufacturing industry stands at about 130,000 te/yr, or assuming this rate were maintained, about 3.1 Mte by 2016, equivalent of over half the total worst case (*Scenario I*) CLP FBA production.

(d) *Strategy and Recommendations*

Block making is the major user of FBA and it would appear prudent to take steps to protect and even increase its market share.

Two means could benefit FBA block making in the future. The first would be to locate any block plants close to the major FBA producers, CPPS and LTPS, in the TMP Development area to reduce transportation costs. Reservation of a site of about 20 ha has been suggested by CLP. A second measure could be reduce the price at which FBA is sold, or given that costs of disposal would amount to at least HK$75/te, subsidies could be considered and still benefit the utilities economically.

Making the use of FBA, if available, in blocks made in Hong Kong mandatory would not be recommended since it might be regarded as unduly restrictive and could simply result in the importation of more red bricks from the PRC.

4.2.3 *Aggregates Replacement*

As a general aggregate replacement in concrete FBA would be restricted to non-structural applications, but could develop a number of uses.

(a) *Economic and Technical Aspects*

Based on past utilisation of FBA abroad[52] and in Hong Kong[23] there are three areas in which appreciable quantities of FBA could be utilised:

- *Sub-Base material in road construction:* Practiced in the UK and Europe, FBA is a useful road base material since it is easy to handle and compact and can be placed in all weather conditions. A free draining material, FBA protects the sub-grade against inclement weather and construction traffic. In certain applications cement stabilisation of FBA in the road base may afford benefits.

- *Free draining material in infrastructural projects:* The free draining and granular properties of FBA favour it over alternatives for placement behind retaining walls and in land drains.

- *Hardcore for temporary standing areas:* Similar to road base applications, FBA can be compacted into temporary standing areas suitable for use in all weathers in construction projects. The hardstanding area can later be capped and used as roadbase.

Economically, use of FBA in these applications is believed to be favourable if alternative materials have to be imported to the construction site.

(b) *Environmental Aspects*

Section 3.2 discussed the issues associated with the transport, placement and compaction of fuel ash. Provided similar standards of site management practice are maintained FBA should present no significant environmental concerns, since it has a larger particle size and reduced dustiness.

(52) Central Electricity Generating Board *"EIA of West Burton 'B' Power Station"* (1989).

(c) *Market Potential*

Given the rate of construction in Hong Kong the potential market is large in comparison to the quantities of FBA produced, although developmental and marketing activities would be required for CLP to prove the benefits of FBA over the alternatives. Relevant Government departments would need to be assured of performance through trials, before appropriate regulatory actions could be taken to encourage the use of FBA.

(d) *Strategy and Recommendation*

The potential market for FBA as an aggregate replacement would warrant a series of trials by CLP to be followed by aggressive marketing initiatives, as appropriate. Given the above, aggregate replacement could consume quantities of FBA that cannot be sold for block manufacture when LTPS coal-fired units come on stream.

4.2.4 *Interleaving Material at Municipal Landfills*

Section 3.2.6 assessed the potential of PFA as an interleaving material at one or more of the three new large municipal landfills planned for Hong Kong where the material cannot be won directly from the landfill site and must be imported. FBA could potentially be utilised in this area as well, either alone or mixed with PFA

(a) *Economic and Technical Aspects*

A number of potential operational problems were found to be associated with the use of PFA as an interleaving material. These were mostly associated with the small particle size of PFA. The granular nature of FBA makes it more akin to soils and CDG that are currently used as interleaving material than is PFA. Specifically, any wet weather trafficking problems and loss of material into the interstices of refuse should not be issues with FBA (see *Section 3.2.6(a)*).

(b) *Environmental Aspects*

Environmental benefits and concerns of utilisation of FBA as an interleaving material will affectively mirror those of PFA. The reader is referred to *Section 3.2.6(b)*. Issues associated with dust nuisance will be reduced over these associated with PFA.

(c) *Market Potential*

Section 3.2.4(c) identified potential demand of 750 te/day at WENT and 350 te/day at SENT (about 0.27 and 0.13 Mte/yr respectively). These figures are well in excess of likely availability of FBA during the early years of LTPS operation. Hence use of FBA alone is likely to be of limited benefit, although if FBA were found to be suitable, any excess produced at the LTPS or CPPS would provide an economic alternative to other imported materials, particularly at WENT.

Conversely if PFA were found to be a suitable interleaving material, mixing with available FBA would only improve its properties as an interleaving material. The option could act as backup to fluctuations in market demand in other utilisation options.

(d) *Strategy and Recommendations*

The use of FBA could be considered concurrently with the recommended consideration of PFA as an interleaving material (*Section 3.2.6(d)*). Since excess production of FBA is likely to be small in comparison to interleaving material demand consideration should given to mixing it either with PFA or other imported interleaving materials.

4.2.5 *FBA as a Reclamation Fill*

The subject of the use of fuel ash as a reclamation fill, above and below water level is discussed in detail in *Section 3.2.9*. Available quantities of FBA are unlikely to amount to that sufficient to complete other than small reclamations or site formation projects. Hence, the use of FBA in reclamation is considered only in the context of its use with PFA or other fills. Further, use of FBA in reclamations would not be favoured over other beneficial uses since its commercial value would not be realised.

Mixing available FBA and PFA in reclamations is unlikely to adversely affect the geotechnical properties of the ash as a fill material since it would only be present at less than 10% of total volume. Chemical properties of both ash types are similar.

Any use of FBA with PFA in reclamations must therefore be seen as an alternative to disposal of FBA that cannot be used elsewhere. It would afford the economic benefit of reduced disposal costs. Its use would only be of benefit when not enough PFA is available since FBA is potentially a much more valuable product.

Market potential and environmental implications were covered in *Section 3.2.9* and FBA should not present any additional concerns.

4.3 *DISPOSAL OF FBA*

Disposal facilities might be required for FBA arisings from CPPS and/or the LTPS at Black Point which cannot be sold or otherwise beneficially utilised. Disposal capacity must also afford backup for all arisings if utilisation markets fail.

FBA is potentially a saleable product and hence, even if it cannot be used in the short term, advantages might be afforded to stockpiling any excess production for possible later use. This could either be effected through the use of a site dedicated only to FBA or by reserving a dedicated area of any PFA disposal facility for FBA.

4.3.1 *The Options*

Disposal facilities for FBA would comprise one or part of one of those identified as a potential disposal facility (*Section 3.3*). Options considered in the study are:

- Separate Area Above Water Level at Tsang Tsui;
- Separate Area within a PFA Landfill Site;
- Dedicated Use of a Quarry Site.

Quantities requiring disposal would be much less than those associated with PFA. The design and operation of any FBA disposal facility would be similar to those at a PFA site where ash is trucked to the site. Environmental concerns would be the same or at a reduced level to those associated with PFA. The above were considered in *Section 3.3* and are not further discussed below unless specific to FBA.

(a) *Separate FBA Disposal Area at Tsang Tsui*

An important aspect of the PFA management strategy (*Section 3.4*) is the continued use of Tsang Tsui until such time as a further disposal facility is actually required. This strategy also allows potential utilisation markets time to develop. This would apply equally to FBA, particularly as the quantities that may require disposal in the early years of LTPS operation would be very small in comparison to PFA arisings. An above water level area to the south of the west lagoon at Tsang Tsui has been suggested by CLP to stockpile excess arisings of FBA.

(i) *Constraints*

Current licence conditions for Tsang Tsui permit the dumping of PFA only, by hydraulic transport from Castle Peak Power Station. Trucking of PFA to the site is allowed only as an emergency measure. Hence use of the site for FBA would require the licence to be extended both for material and to facilitate trucking to the site.

The existing vehicular access to Tsang Tsui comprises a dirt track. This would require upgrading if large quantities FBA were to be trucked to the site although this situation would improve if use were made of the new Southern Access road. Alternative transport options such as belt conveying or barging are unlikely to be warranted on the grounds of the small quantities requiring disposal.

(ii) *Recommendations*

If Tsang Tsui is to continue to be used for PFA disposal (in either current capacity or extended capacity configurations), then it is recommended an area be set aside for FBA stockpiling. Overall lifespan of Tsang Tsui would not be significantly affected since the quantities requiring disposal would be small.

(b) *Separate FBA Disposal Area at PFA Landfill*

Any of the potential landfill sites identified for PFA disposal could also serve CLPs needs for FBA disposal capacity without significantly affecting lifespans. A dedicated area of sufficient capacity could be set aside as suggested at Tsang Tsui. Constraints, environmental concerns and economic issues are as set out in *Section 3.3.3(b)*.

(c) *Dedicated Use of a Quarry Site*

The two quarry sites identified in the site search study, Q1 and Q2, have capacities, at 5 and 4 Mm^3 respectively, sufficient to take all FBA arisings from the LTPS and CPPS over a twenty year period of LTPS operation under the ultimate worst case conditions of no utilisation whatsoever. As such, either could be dedicated for FBA disposal given resolution of constraints detailed in *Section 3.3.4*. Economically the cost would be higher than disposal at Tsang Tsui.

Environmental benefits afforded by quarry restoration would only be realised in the long term if FBA is disposed of permanently, rather than stockpiled and later utilised.

4.4 INTEGRATED 20 YEAR MANAGEMENT STRATEGIES

4.4.1 Introduction

Sections 4.2 and 4.3 indicate that utilisation and disposal options for FBA are available and the quantities involved mean the issues are less problematical than those associated with PFA. The similar chemical properties of the two ash products mean that FBA can be put to similar uses as PFA, although its physical properties make it a much more valuable by-product.

4.4.2 Beneficial Utilisation of FBA

Utilisation of all CLPs FBA arisings is possible under either firing scenario given encouragement for its use in block manufacture and as an aggregates replacement. Further FBA remaining could be utilised in conjunction with PFA as an interleaving material or reclamation fill.

Utilisation rates cover two different situations:

- *Present Utilisation* represents the minimum rate of FBA usage foreseeable at this time based on historical utilisation at CPPS. This has been taken at the current rate of 130 kte/yr. It is difficult to envisage a situation where utilisation would be reduced from this level given the current economic advantages of using FBA in block manufacture and those subsidies that could be instituted and still merit consideration ahead of disposal. Other utilisation markets can only grow.

- *Potential Utilisation* incorporates utilisation of the remaining arisings in expanded block manufacturing operations, light aggregates and uses with PFA.

Figures 4.4(a) and 4.4(b) show the effects of the likely utilisation on the quantity of CPPS and LTPS FBA remaining under *Scenario I and II* firing configurations respectively.

4.4.3 Disposal of FBA

Potential disposal options for FBA not utilised are linked closely to those selected for excess PFA arisings since, in most instances it will be preferable to dispose FBA in separate areas of any PFA disposal facility. The effect of the lifespan of any PFA disposal facility is unlikely to be significant, particularly in the early years of LTPS operation. For example, Tsang Tsui lifespan would not change from those given in *Table 3.4(b)* with estimated extra disposal requirement (out of 5.5 Mte) at 100 kte and 43 kte under *Scenario I* (by 1998) and *II* (by 1999) respectively.

PFA landfill sites with lifespans of over 10 years from when Tsang Tsui is full would see their working life cut between 5 and 10% at most. This does not effect the ranking given in *Section 3.4*.

Either of the two quarry sites could accommodate all likely excess FBA arisings to beyond 2026.

Hence preferred disposal routes for excess FBA are ranked as follows for both *Scenario I and II.*

1) Separate area at Tsang Tsui - current licence capacity

2) Separate area at Tsang Tsui - extended capacity

3) Separate area at PFA Landfill

4) Dedicated FBA Quarry disposal site

Before any of these disposal routes could be instituted the constraints to development summarised in *Section 3.4.3, Table 3.4(b)* and *Section 4.3* would need resolution.

4.4.4 FBA 20 Year Management Strategy

The aim of the FBA management strategy is again to maximise utilisation, whilst minimising the environmental and economic impact of disposal facilities by delaying their construction as long as possible within the study period (1992 to 2016).

a) Beneficial Utilisation of FBA

As detailed in *Section 3.4.2* it is quite conceivable that all FBA can be utilised by the Hong Kong construction industry given appropriate marketing. A utilisation rate of about 130 kte/yr, under the most pessimistic foreseeable market conditions, would more than halve the total arisings of CLP's FBA requiring disposal. Ongoing strategic actions recommended, beyond those of *Table 3.4(e)* are given in *Table 4.4(a)*.

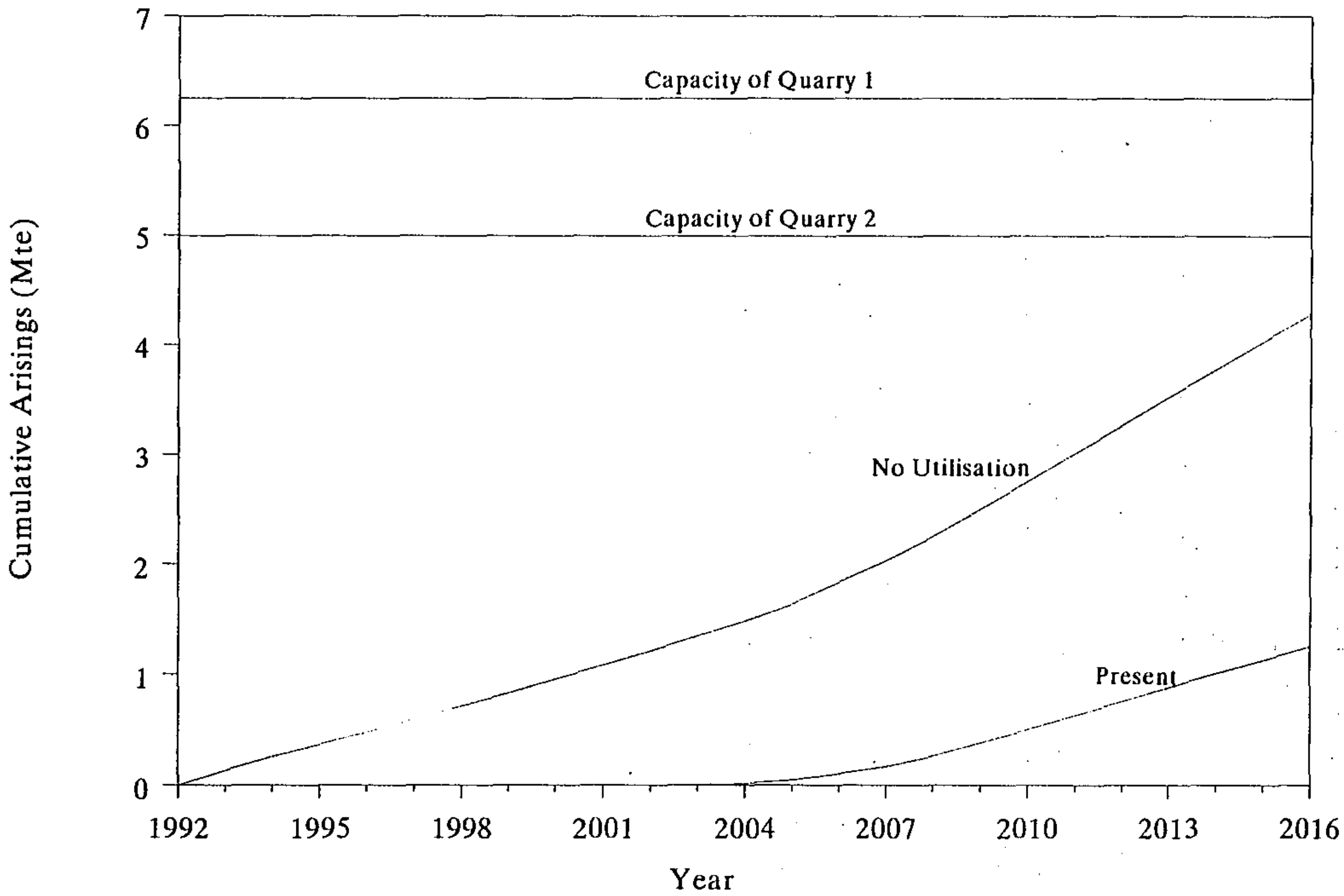


Figure 4.4a – FBA Disposal Requirements and Quarry Site Lifespans – SCENARIO I

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

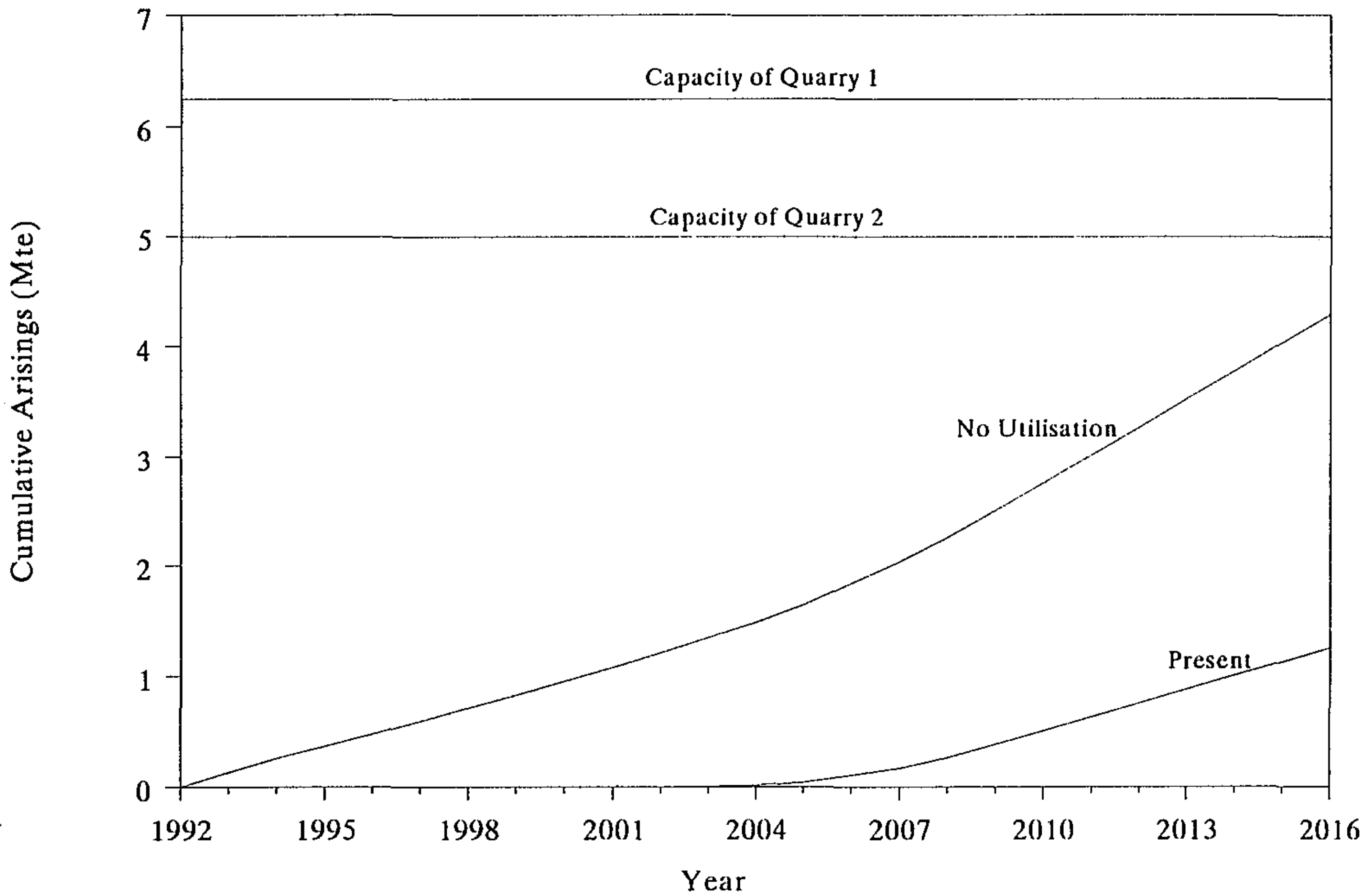


Figure 4.4b – FBA Disposal Requirements and Quarry Site Lifespans – SCENARIO II

ERM Hong Kong
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

Table 4.4(a) FBA Utilisation Strategy – Actions	
China Light & Power Company	**Government**
Concrete Blocks	
• Investigate market potential and economic viability of existing operation. Consider subsidies e.g. disposal cost.	• Reserve site in TMP Development Area for new block plant.
Aggregates Replacement	
• Tests and Trials to confirm suitability/marketing	• Appropriate encouragement on completion of trials
Interleaving Material with PFA	
• Marketing/trials, as PFA (*Table 3.4(e)*)	• Appropriate encouragement on completion of trials
Reclamation with PFA	
• Marketing/trials, as PFA (*Table 3.4(e)*)	• Appropriate encouragement on completion of trials

(b) *Disposal Facilities*

Earliest dates at which detailed planning for any FBA facilities would be required are as for PFA – 1995 under *Scenario I* and 1996 for *Scenario II* – allowing three years for planning and construction.

Table 4.4(b) summarises recommended strategic actions in addition to those of *Table 3.4(f)*.

Table 4.4(b) FBA Disposal Strategy – Actions	
China Light & Power Company	**Government**
Tsang Tsui	
• Apply for licence incorporating FBA disposal area.	
Landfills & Quarries	
• Apply for provisional licences incorporating FBA disposal area	

5 *FGD GYPSUM MANAGEMENT*

5.1 *INTRODUCTION*

Gypsum is the principal by-product of the Limestone/gypsum FGD process. Natural, as opposed to FGD gypsum is traditionally used in a wide range of construction and industrial applications, from the manufacture of cement to use as an additive in beer. There are applications where FGD gypsum can replace natural gypsum sometimes to economic advantage.

If the limestone/gypsum process were fitted to all coal-fired units at the LTPS, upto 0.7 Mte/yr of high-grade gypsum could be produced under *Scenario I* (all coal firing, 1% sulphur coal, high growth in electricity demand) giving a total of up to 8.5 Mte from 1996 to 2016. Corresponding figures for *Scenario II* are up to 0.35 Mte/yr, a total of about 4 Mte in 2016, although production would not commence before 2004. In addition HEC's new units at Lamma could be producing, up to 0.15 Mte/yr if the latter two planned 350 MW units are also fitted with Limestone/Gypsum FGD.

The figures derived above refer to the standard Limestone/Gypsum FGD system, but will be approximate since actual output will depend on the purity of limestone reagent and sulphur content of the coal. We have been conservative in our estimations of waste arisings (see *Section 2*) and the quoted figures refer to the worst case coal (1% sulphur) and likely worst case limestone specification.

CLP are considering a number of variants on the standard Limestone. Gypsum Process which could affect the quality or quantity of any product gypsum or whether any solid gypsum would be produced:

- ***Seawater make-up as an alternative to use of towns water***: If product gypsum is not to be beneficially utilised and detailed design confirms its feasibility then seawater could be used for a proportion of the make-up water requirement. The effects, so far as this KIA is concerned, would be to increase the salinity of the product and possibly its chloride content. Quantities would remain within those values stated above.

- ***Re-dissolution of product gypsum in the seawater and discharge to sea via the cooling water outfall.*** In this variant on the Limestone/Gypsum Process the product gypsum is dissolved in the cooling water system. The calcium and sulphate ions, of which gypsum mainly comprises are major constituents of seawater. This option could operate with or without wastewater treatment to remove a proportion of the metals content. No solid gypsum byproduct is produced.

- ***Seawater FGD System***: This variant on wet FGD scrubbing uses a seawater/lime slurry to scrub the flue gases. The product gypsum remains as a suspension/solution and is discharged to sea. Issues on the marine impact of this system are discussed in the parallel water KIA. If acceptable, this process removes the requirement to dispose of any solid by-products to land, whilst also reducing LTPS towns water demand. A small proportion of the metal content and residual fly ash could be removed in a prescrubber and the effluent treated if required by the Water Quality KIA.

Previous studies have identified certain potential markets for FGD gypsum in Hong Kong and abroad. For example, HEC are believed to have entered into a buyback agreement with a Japanese limestone supplier for the gypsum output of the first of its planned three new coal fired units. The gypsum would be utilised for wallboard manufacturer in Japan. However, market development and economic issues mean prediction of beneficial utilisation is uncertain. Generic disposal options for FGD gypsum are well known and were discussed in the IAR[3]. Investigations have been made of several alternative disposal sites and preliminary design of facilities completed.

FGD gypsum is produced as a direct result of the institution of measures to protect the environment through the abatement of SO_2 emissions that can lead to acidification of local and transboundary environments. Hence, it is particularly important that resulting disposal routes for FGD gypsum do not produce significant impacts in themselves. Otherwise an airborne problem (SO_2 emissions) is simply transformed into a land (gypsum) and/or aqueous (leachate) problem.

5.2 *BENEFICIAL UTILISATION OF GYPSUM*

5.2.1 *The Options*

The limestone/gypsum process is the World's leading FGD system, fitted to many thousands of megawatts (MW) of generating capacity, mostly in highly industrialised nations such as the USA, Japan and Germany. As described in *Section 2* the particular system configuration can be designed to produce a product of varying specification dependant on the ultimate use or disposal route. One of the main advantages of the process, that accounts for its leading market position, is that a by-product of commercial value can be produced where there is a market. In Germany and Japan most FGD gypsum is used in the manufacture of wallboard for use in the building trade. However such uses are influenced by a number of commercial considerations. These include the size of the local market, the cost of transport for delivery and the availability of competing alternative materials.

The IAR[3] assessed the potential of FGD gypsum utilisation in Hong Kong in the context of the current natural gypsum market. At 126,000 te in 1989 and 72,000 te in 1990 the market is small in comparison to the quantities likely to be produced at the LTPS. Much of the imported gypsum is used by China Cement Company in the manufacture of cement with the only other significant user being in the building trade as a finishing material (plaster). Wallboard (plaster board) is not a major building material in Hong Kong and there is no indigenous wallboard manufacturing industry.

The IAR also addressed certain other potential uses for FGD gypsum, but concluded all would require a series of tests and trials even before a market could begin to be developed. It concluded that any significant use of FGD gypsum in Hong Kong must be regarded as speculative at this time and that long term markets in Hong Kong or overseas could not be guaranteed.

This study has re-examined the potential uses of the IAR and some others besides. Issues associated with each potential utilisation market identified by previous studies[(3),(7),(17),(53)], are briefly discussed below.

5.2.2 *FGD Gypsum in Wallboard Manufacture*

In Japan and Germany there are large wallboard markets. The widespread and increasing installation of limestone/gypsum processes has largely lead to FGD gypsum replacing the natural gypsum previously used. Environmental benefits have been afforded to both the power generation industry, in the form of SO_2 reduction, and in the form of reduced quarrying of natural gypsum. The use of FGD gypsum has become widely accepted after some early public concerns over origin and colour. In order to be acceptable FGD gypsum must be of high purity (>95% $CaSO_4 \cdot 2H_2O$, dry basis) and low moisture (4% absorbed water) and chloride content. This necessitates the use of a high grade raw material limestone and intensive 'washing' and 'drying' of product gypsum to ensure removal of salinity and to meet moisture content requirements.

Construction in Hong Kong rarely incorporates the use of wallboard. At present all wallboard is imported to Hong Kong, mainly from the USA. The market is small at less than HK$35 million. Where other countries use wallboard, Hong Kong mostly uses cheap imports of plywood.

Utilisation of LTPS FGD gypsum in wallboard could potentially result from two routes; either export (see *Section 5.2.7*) or the development of production facilities in Hong Kong. During the study period CLP have received two serious enquiries from wallboard manufacturers thinking of diversifying their business into South East Asia, either through a Hong Kong plant or one located nearby in the region.

A wallboard production plant could utilise large quantities of FGD gypsum, but two constraints would need to be overcome:

- *Market Outlet*: product wallboard would need to be sold in Hong Kong and/or exported. Creating a significant market in Hong Kong would require major shifts in construction techniques and would likely only occur if supplies of wood and plywood were to become expensive or restricted. There are some obvious advantages to such restrictions notably in preservation of South East Asian rainforests. Existing overseas markets for wallboard are beyond the immediate Hong Kong region, with Japan being the nearest major user. Transportation costs alone could reduce the competitiveness of a Hong Kong product since Japan, and other large markets in the USA and Europe, is rapidly being swamped by gypsum output from its own power plants as more are fitted with FGD.

- *Capital*: Planning, construction and development of manufacturing facilities requires land and capital. Given the existing market conditions (see above), it is likely that CLP may need to subsidise a plant, having first found a market for the product. In view of the above, the Consultants do not perceive wallboard manufacture as a viable management strategy at this time. The same arguments would apply to another potential use identified for FGD gypsum, utilisation as

(53) Pietrzeniuck, H.J., "Utilisation of Desulphurisation and Denitrification Technologies" for West German Federal Environment Agency (1985).

a binder for emission free Particle Board (as an alternative to formaldehyde)[38].

5.2.3 *FGD Gypsum in Cement Manufacture*

Probably the second most significant use of gypsum is in the manufacture of cement where it is included to delay setting. This use has been adopted in Germany where natural gypsum is partially replaced by FGD gypsum[17]. Demand for gypsum in cement in Hong Kong would not exceed 100,000 te/yr with CCCs kiln at capacity and they have indicated that they would not accept FGD gypsum on technical grounds (principally concerned with purity and particle size distribution). Similar reservations would be expected from plaster manufacturers where colour could also be important. Therefore, this cannot be relied upon as a management strategy as yet, although demonstrations and concerted marketing to CCC to alleviate technical and economic concerns could be beneficial in the long term.

5.2.4 *FGD Gypsum as a Fill Material*

The IAR[3] investigated the use of FGD gypsum as a fill material when combined with PFA. It was concluded that its use (mixed with PFA) as fill, needs to be investigated and its feasibility demonstrated by field tests under Hong Kong conditions. Commenting on the IAR the GEO remarked[54].

> *"... While the use of PFA as fill below water is still in dispute, it is premature to consider the use of FGD gypsum. I suggest that attention should be concentrated on gaining wider acceptance on the use of PFA before introducing the FGD component."*

The Consultants support this view, but given the size of the reclamation fill demand in Hong Kong the issue of acceptability should be investigated if use of PFA is approved and adopted.

Trials could be conducted with:

- FGD Gypsum and PFA;
- FGD Gypsum and FBA;
- FGD Gypsum, ash and sludge;
- FGD Gypsum, ash, sludge and lime.

The latter addition of lime effectively stabilises the mixture (i.e. transforms it to a cementitious material) and would make it leachate resistant. Further, its properties would enable its use as a low grade structural fill such as for road embankment construction. It is believed that some FGD gypsum is utilised in this manner in Japan[17].

Consideration was given during the study for the potential utilisation of FGD gypsum as an interleaving material at municipal landfills. However experience from the UK, at Cotham in Nottinghamshire[31] indicates that sulphate reducing bacteria in municipal waste gives rise to odour problems from the generation of hydrogen sulphide. Specific trials would be required to determine what levels of sulphate could be used without elevating hydrogen sulphide emissions before any firm recommendations could be made.

(54) Principal Government Geotechnical Engineer (S.B. Massey) "*Comments on IAR – Volume 3*" Ref (21) in GCP 1/10/445III (18 October 1991).

5.2.5 *FGD Gypsum in Artificial Reef Construction*

The idea of utilising power station wastes for fisheries enhancement was discussed in the IAR[3]. Mixtures of FGD Gypsum, PFA, cement, and sludge have or are being investigated in the United States, Japan, Bermuda and the UK, but no such reefs have been constructed on a commercial basis as yet although several concrete reefs (without FGD gypsum or sludge) have been constructed in Japan to provide seafood.

Plans are underway to build Hong Kong's first artificial reef and environmental benefits to marine water quality and fish are perceived by the project co-ordinators, Agriculture and Fisheries Department and Hong Kong University[55]. The proposals incorporate a plan to utilise PFA in the concrete from which the 100m x 100m x 2m high reef at Cape D'Aguilar is to be constructed.

Trials have shown that once mixed with concrete, trace metals in PFA do not leach into the seawater. Trails are continuing the University of Southhampton (in collaboration with the UK's two major power generators, National Power and PowerGen), using cement stabilised blocks of PFA, FGD gypsum and sludge. Concrete blocks made from this material have been used to construct an experimental artificial reef in Poole Bay[56]. After more than two years no adverse effects regarding leachate of trace metals or uptake by marine organisms have been reported. The UK work follows earlier studies with such blocks carried out by researchers at the University of New York at Stony Brook, which also concluded that no adverse impact had resulted to the marine environment in respect of trace metals after limited trials.

Results to date have been promising, but the situation vis a vis the LTPS remains the same as at the IAR stage. Artificial reef construction is not yet a feasible FGD gypsum by-product strategy since it is likely that tests, lasting several years, would be required in the local Hong Kong context.

5.2.6 *Export*

The brief discussion above indicates that the prospects of developing a local market for FGD gypsum are not good, at least in the early years of LTPS operation. The remaining alternative to disposal is to export to net importers of gypsum. Whilst periodic exports of FGD gypsum would be of use to CLP in reducing quantities requiring alternative disposal, export would not merit as a management strategy unless a long term secure export market were found.

It is understood that Hongkong Electric have negotiated a contract to purchase high quality limestone from Japan for its planned FGD facilities. The supplier has undertaken to take back high purity product FGD gypsum for use in the Japanese market (mostly wallboard). Quantities of off-specification gypsum and water treatment sludges will however require disposal in Hong Kong. Back-up disposal facilities are being sought by HEC in the event of contract failure.

(55) South China Morning Post, *"Marine Life Prepares for First Artifical Habitat"* (7 March 1992).

(56) University of Southampton *"The Artifical Reef Project – Poole Bay"* for Powergen and National Power (1991).

China Light & Power have also investigated the potential of such 'buy-back' arrangements and in the event of the limestone/gypsum process being installed would strongly consider the option. However, there are concerns about potential problems with such arrangements, making it likely that disposal facilities would, in any event, still be required for back-up:

- *Technical constraints*: Buy-back arrangements tie a utility to purchasing limestone from a particular source and to produce a product gypsum of a set specification. Past experience has shown that about 10% of product will not meet commercial specifications and would require disposal. Further, varying process configurations to allow the use of seawater in place of towns water in the process would be restricted. Added processing equipment is required to meet specifications in respect of salinity, moisture content and large storage facilities would be needed to temporarily store product prior to export in a reasonably sized vessels.

- *Security*: Buy-back arrangements are designed to provide a secure outlet for a utilities gypsum output. However, contracts cannot be entirely binding and there must be some doubt as to how long the arrangement can last. Japan has a growing output of FGD gypsum produced by its own utilities and it is possible the Japanese market could develop along the lines of the German market, which is now saturated. Currently, excess German wallboard is exported to other countries in Europe, but these nations are also fitting FGD equipment of their own and the markets are not secure, particularly since transportation costs are a major factor, in cost competitiveness.

- *Expense*: CLP have indicated that costs associated with buy-back arrangements are inflated over alternatives, both in the cost of limestone, transportation to the market and in terms of the operating costs of the FGD plant. These extra costs would inevitably be reflected in electricity prices.

Whilst the Consultants would recommend CLP to enter into an export arrangement, it cannot be regarded as a secure alternative to the development of disposal facilities supplemented by development of local markets.

5.3 DISPOSAL OF GYPSUM

Disposal facilities will be required if a solid gypsum producing FGD system configuration is adopted. The quantities concerned would range from up to 10% of arisings, if an export arrangement were negotiated and successfully carried out, to 100% of arisings for the standard and seawater makeup Limestone/Gypsum FGD systems. Disposal facilities must also afford backup for arisings were an export agreement or other utilisation strategy to fail.

FGD gypsum is a potentially useful product of commercial value perhaps greater than that of ash by-products. Hence, whilst it may not be able to be utilised in the short term, there could be benefits to be gained in the long term by disposing of FGD gypsum in a form such that it could be retrieved at a later date. However, FGD gypsum for commercial use must meet certain quality specifications required by the process for which it is intended. As described above meeting these criteria requires the utility operator to use high quality reagents and pursue an intensive washing process to ensure compliance. This can be costly in respect of operating costs and hence utility operators will not wash product gypsum destined for disposal. Any later user of a disposed stockpile would first need to conduct this washing, reducing the attractiveness of the stockpile as compared to natural gypsum.

To avoid contamination of the ash by-products the Consultants have restricted their study to look at dedicated gypsum disposal facilities or separate areas within a multipurpose disposal facility.

Unlike PFA, which has been produced in Hong Kong for many years and disposal options and techniques are well know and understood, gypsum disposal is new to Hong Kong. Therefore prior to considering specific disposal options and sites, worldwide disposal practices are reviewed, together with the principle technical considerations, environmental properties and potential concerns.

5.3.1 *Gypsum Disposal Practice*

The technical considerations, environmental impacts and concerns of disposing of gypsum mirror those of other bulk solid materials, but account must be taken of the particular chemical and physical nature of gypsum.

(a) Worldwide Gypsum Disposal Practice

(i) Landfill

As discussed in *Section 5.2* Limestone/Gypsum FGD systems are predominantly confined to the major industrial nations of the USA, Japan and Germany. These countries have adopted different approaches to both disposal and utilisation.

In Japan no FGD gypsum is known to be landfilled mainly because utilisation is highly developed due to lack of landfill space. In the USA most systems produce sulphite sludge ($CaSO_3 \cdot \frac{1}{2}H_2O$ – with a high chemical oxygen demand) by the 'wet' process. The resultant slurry is usually lagooned in large ponds. The only comparable situation to that at the LTPS is at the Scholz Plant of the Gulf Power Plant (which uses a variant system known as the Chiyoda 121 process) which produces gypsum which is dewatered and disposed of or stored by placing it within a stack. The stacking procedure involves the pumping of a treated gypsum slurry into a retention pond where the solids settle and the decanted liquor is removed. The pond which receives the slurry is divided by a dyke to provide an active and a drained pond. After the material in the latter has drained, it is pulled to the side to raise the sides of the pond. The two ponds are used alternately in this fashion until the stack reaches its ultimate height. In Florida some phospho-gypsum stacks cover 20 to 120 hectares to a height of 30 to 45 metres.

In Germany most FGD gypsum is utilised, the exception being that derived from power stations fired on brown coal (rather than the hard coal CLP burn). A plant at Rheinbraun was given permission to commence disposal of brown coal gypsum (which is too contaminated for most commercial uses) into an opencast lignite mine near Aachen. This was a temporary permission requiring a reconsideration in five years. This disposal operation is known to have produced a cementitious material which is highly impermeable and thus does not give rise to leachate concerns. The implication is that it was mixed with PFA and/or cement first. Up to 3m of overburden will be placed on top of the gypsum to facilitate restoration.

The North-Rhine, Westphalia Water and Wastes Agency requires that all gypsum disposal be at least 1m above ground water levels to ensure no ground water contamination. Bottom sealing by mineral layers or membrane to prevent seepage to ground water and top sealing by mineral layers are required to prevent rainwater ingress to gypsum.

Although no FGD gypsum is produced in the UK at present, substantial quantities of chemical gypsums; phospho-gypsum and fluoro-gypsum; are produced as by-products by the chemical industry.

- *Phospho-gypsum:* This is produced as a by-product of phosphoric acid manufacture following the reaction of sulphuric acid on phosphate rock. It is essentially calcium sulphate dihydrate (as would be CLP's) contaminated with residual phosphate, fluorides and cadmium; the proportions depend on the source rock.

  ICI Chemical and Polymers Division (Billingham) produce a moist powder (20-25% water content) which is taken by trucks to the Cow Pen Marsh disposal site, some 5-6 km away from the plant, where it is end tipped and compacted in 2-3m layers by a bulldozer. Approximately 50,000 tonnes/yr of other inert industrial waste is co-disposal at this site.

  The site has been operational since 1961 and covers an area of some 200ha. Maximum depth of phospho-gypsum is about 20m and side slopes are approximately 1 in 5. Perimeter drains and settlement tanks are used to collect run-off and remove suspended solids prior to discharge to a tidal estuary by consent with the Water Authority. Uncontrolled vehicle movements have caused dust problems in the past.

  Cow Pen Marsh is largely reclaimed tidal marshland used for grazing sheep. The soils are stripped in advance of tipping and replaced directly on to the phospho-gypsum to a depth of about 450mm. Because of the improved drainage characteristics the land can now be used for arable cropping; wheat, barley and oil seed rape are currently grown.

- *Fluoro-gypsum:* This material is derived from the manufacture of hydrofluoric acid produced by the action of sulphuric acid on fluorspar. Two processes have been used by ICI - the now superseded wet process which produced calcium sulphate dihydrate (gypsum) and the current dry process which produces calcium sulphate (anhydrite). Approximately 100,000 tonnes/yr of fluoro-gypsum and anhydrite were deposited at East Clifton Marsh site until the early 1970's. The waste was tipped dry by lorries and spread by bulldozer into four mounded areas with a maximum height of 10m and side slopes of about 1 in 6. When tipping ceased the material was covered with a layer of PFA dug from an old slurry lagoon. The depth of PFA varies between 400mm and 1000mm. In 1974/75 the site was hydroseeded to grass, trees were planted into soil pits. Both grass and trees have grown well and the site is currently grazed by sheep. A perimeter drain collects surface run-off/leachate which has a milky appearance - this may be due to the washing out of lime added to the fluoro-gypsum to correct residual acidity.

- *FGD Retrofit Programme:* As part of its compliance with the EC (European Commission) Directive on Large Combustion Plant and the UNECE (United Nations Economic Commission for Europe) Helsinki and Sofia Protocols (the so called "30 Per Cent Club") to reduce SO_2 emissions, FGD retrofits are currently underway or planned at certain large coal-fired power stations in the UK. The utilities concerned intend that most of their FGD gypsum will be utilised in wallboard manufacture. However in order to afford back-up, contingency disposal facilities were investigated. Feasibility studies identified several on-land disposal options (for either gypsum alone or mixed with PFA):

  - landfilling of quarries, sand and gravel pits and other derelict land;
  - filling voids such as underground mines or open cast mines;
  - foreshore reclamation;
  - surface mounding.

  Co-disposal of gypsum with domestic refuse was ruled out on the basis that high levels of sulphate would, in the presence of organic matter and sulphate reducing bacteria, generate noxious sulphides including the toxic gas, hydrogen sulphide.

  The on-going retrofit at Drax Power Station has a 'back-up' landfill site close to the plant.

(ii) Dissolution

At the Norsk Hydro phosphoric acid plant in Immingham, UK, disposal commenced in the 1950's by pumping phospho-gypsum slurry into shallow lagoons close to the works. This method soon proved to be unsatisfactory because of dewatering difficulties. The material was then pumped via a pipeline directly into the deep water channel of the Humber. Approximately 500,000-750,000 tonnes/yr of phospho-gypsum slurry (10% solids) was discharged until 1986 when production of phosphoric acid ceased. Discharge was carried out under a local Water Authority consent and frequent monitoring was carried out to check estuarine river water quality and sedimentation. No adverse affects were found, probably due to the strong tidal currents which prevail in the Humber. This contrasted with discharge from a similar Norsk Hydro plant at Avonmouth where sedimentation problems did arise because of poor dispersal from the pipeline outfall. This discharge ceased in 1980.

(b) Environmental Issues Specific to FGD Gypsum

Environmental considerations relating to the disposal of gypsum in landfills or to the marine environment centre on the following key issues related to the physical and chemical nature of FGD gypsum derived from past experience:

- impact of dissolved species on the marine environment;
- noise and dust generation from transport;
- leachate, dust generation and visual impacts at landfills.

These issues are considered in general below, if appropriate and in detail in the following sections specific to each potential disposal facility.

5.3.2 *The Options*

Disposal facilities considered for FGD gypsum have encompassed those identified as potentially suitable in CLP's site search (see *Section 3.3*) whilst considering the actual likely arisings of gypsum. Specifically options considered in the study are:

- *Landfills*
  - Dedicated Gypsum Landfills or Separate Area at an Ash Disposal Landfill
  - Restoration of Quarries/Borrow Areas
- *Separate Area at Tsang Tsui Ash Lagoons or new lagoon sites*
- *Disposal at Sea*
  - Dissolution in Seawater and Discharge via Cooling Water Outfall
  - Marine Dumping in Hong Kong Waters or International Waters

Lagooning gypsum at proposed marine lagoon sites (ML1-4 as per *Section 3.3.2*) would create similar environmental concerns as associated with PFA at these sites and is not recommended (see *Section 3.3.2*), nor considered further.

The separate area at Tsang Tsui Ash Lagoons option was considered appropriate for the management of excess (to that is utilised) FBA arisings in *Section 4.3.1(a)*. It is suggested here that gypsum arisings at the LTPS, which would amount to about 40% of LTPS PFA arisings, would not facilitate the practical designation of a separate area for gypsum disposal on economic grounds given the requirement to keep the use of the lagoons flexible for the storage and harvesting of PFA. About 10 ha of space would be required to allow the use of a wet stacking method.

However, were *Scenario I* adopted a facility would be required by 1996. Setting aside a smaller area of the lagoon may be the only possible management strategy until such time as a larger or dedicated disposal facility could be constructed.

5.3.3 *Landfilling of Gypsum*

(a) *General Considerations*

(i) *Dry Placement*

Gypsum behaves as a coarse silt or fine sand. At the landfill, it can be placed and compacted (except for slurrified gypsum from pipeline see part (d)) using conventional earth moving equipment including trucks, bulldozers and vibrating rollers.

Transported as "dry" conditioned material in trucks of appropriate design, there should be little difficulty in handling gypsum. Protection of the surface of the material while it is being transported for more than a few minutes is considered essential, to prevent both drying out and ingress of rain water.

World experience indicates that the optimum moisture content for gypsum placement and compaction is between 15 and 20%. Adding water to aid compaction at a landfill site will be difficult as a water supply on site will be required and a considerable amount of water will be consumed (over $100m^3$/day for 8 unit operation). It is therefore proposed that gypsum for disposal should be only dewatered to the higher 15 to 20% moisture content at the LTPS site prior to taking off site.

Once the LTPS is operating field trials should be carried out to determine the optimum moisture content for compaction of gypsum produced from the LTPS which will have its own process specific properties. Other than physical stability, the main concern of landfilling is its impact on water quality i.e. release of soluble species to surface water (or groundwater).

Gypsum is sparingly soluble, having a maximum solubility of about 2g/litre at 25°C. Passage of water through a deposit of gypsum will produce a leachate with a fairly high level of dissolved solids (primarily calcium and sulphate). Trials previously conducted indicate that two to three times as much sulphate would leach from gypsum than from PFA. However, there appears to be a relatively small transfer of the metal and trace species from the solid to the liquid phase broadly akin to that from PFA. The concentration of suspended solids and the chemical oxygen demand (COD) of the leachate may be significant. The source of the COD is most likely due to residual levels of calcium sulphite ($CaSO_3 \cdot \frac{1}{2}H_2O$). Nutrient concentrations (e.g. nitrate and phosphate) are low.

Section 2.5 gives chemical analyses of gypsum and gypsum leachate samples from existing FGD systems and estimates of the gypsum composition from the proposed installation at Black Point. Although the samples from Riedersbach and Voerde TPSs are not directly comparable to the expected gypsum from the LTPS due to different compositions of reagents and to a lesser extent coal, some interpretation can be made.

Both the Riedersbach and Voerde FGD gypsum samples had a sulphate (SO_4) content of >50% and moisture content of <9% indicating the oxidation reaction was virtually complete and the de-watering process had produced a final product similar to that proposed for the LTPS. The chloride concentrations were low (<40ppm) and this might not be the case at the LTPS particularly if seawater makeup were to be used.

The leachate samples indicated that relatively small proportions of the solids were transferred to the liquid phase, the major species being calcium and sulphate.

The major metals in the gypsum were silica, iron and aluminium. The leachate samples gave low concentrations of all metal species. In terms of landfill disposal, this suggests that movement of species from the solid to the liquid phase would be minimal, apart from the calcium and sulphate.

A very high chemical oxygen demand (COD) was present in one sample – 1100 mg/l. However it has been suggested that organic additives or corrosion inhibitors utilised in the process may be contributing.

It is likely that leachate collected from a disposal site would require some form of treatment before discharge to a water course. This treatment could basically comprise solid/liquid separation, such as settling tanks and possibly aerators. As any oxygen demand would most probably be of chemical, rather than biological origin the options include forced aeration or the addition of a chemical oxidising agent such as peroxide. Further treatment, such as pH adjustment, flocculation and precipitation and possibly ion exchange or evaporation stages may be necessary to comply with the TM effluent discharge requirements. The quantities of leachate generated will depend on the type of disposal site, permeability of the placed material and the infiltration of ground and surface water. Disposal sites should be designed and operated in such a manner as to minimise leachate production (see *Section 3.3.3(a)(iv)*).

The risk of groundwater contamination can be controlled by limiting the quantity of leachate generated. The landfill will need to be engineered to direct surface runoff from the site and to limit water ingress by progressive restoration. If necessary, it can be lined to contain the leachate.

The contained leachate can be drained at the base of the landfill and channelled towards a system of leachate collection pipes, thus enabling it to be pumped back up to the landfill surface or treated at a leachate treatment plant either at the landfill or at the LTPS to reduce any residual COD remove suspended solids. The conceptual design of a dry gypsum landfill disposal site is shown in *Figure 5.3(a)*.

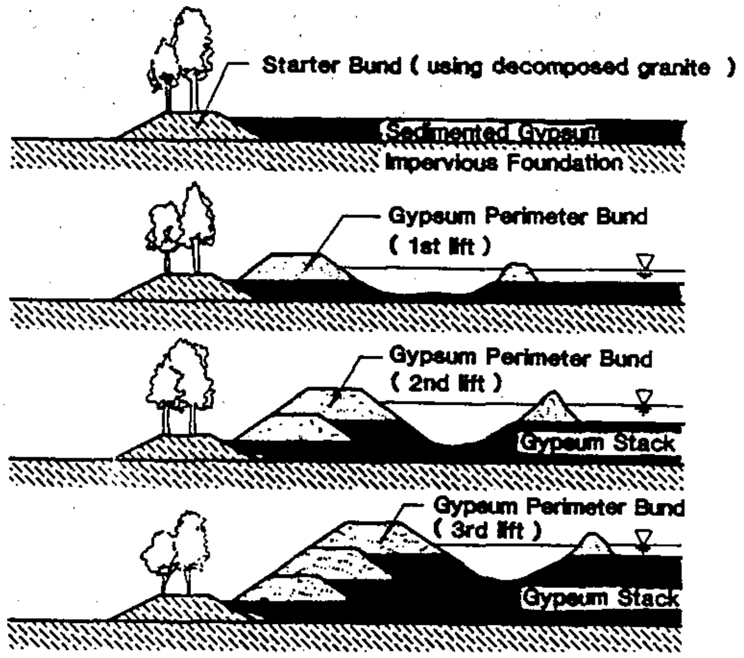
In the design of disposal sites the high concentrations of sulphate should be taken into account. Any concrete used in the drainage system would have to be sulphate resistant and could require further protection such as wrapping. The use of alternative materials, such as fire clay products, should be investigated.

Other environmental concerns of landfilling gypsum are the emission of dust and noise arising from the disposal process itself and from uncontrolled movements of vehicles on site. With the past experience in control at PFA landfills, dust and noise arising from gypsum landfill should also be able to be effectively controlled by institution of site management methods detailed in *Section 3.3*.

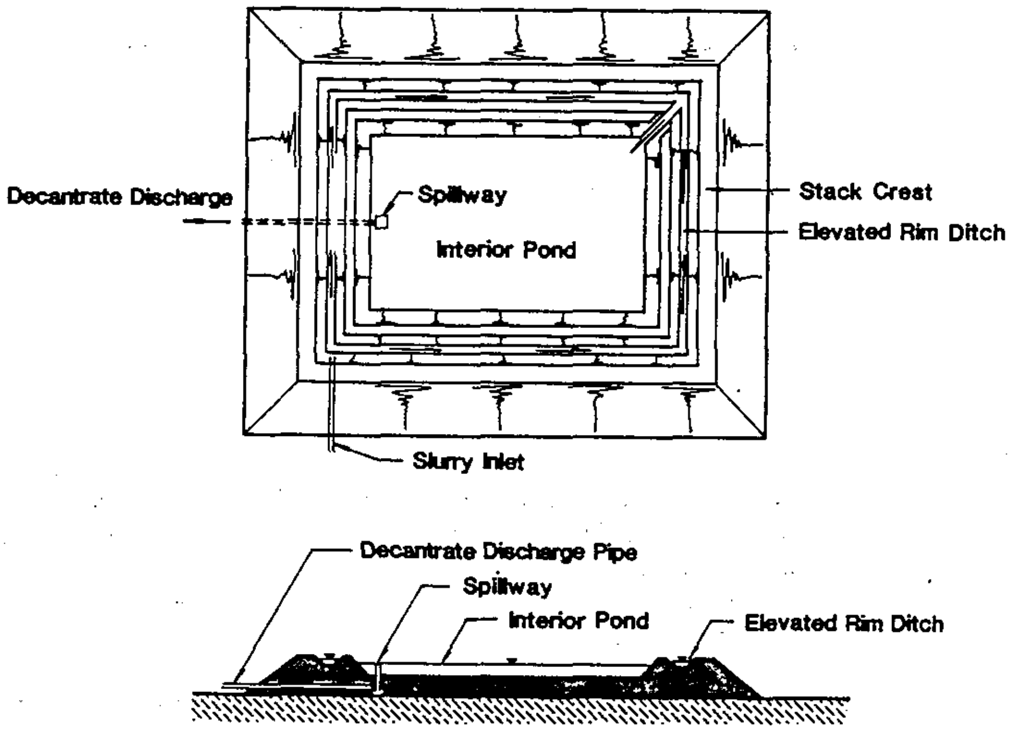
(ii) Wet Stacking Method

This method would be suitable for sites close to the LTPS site and emulates the wet stacking of phosphogypsum, a by-product of the manufacture of phosphate for the fertilizer industry. This method has been practised in the USA for more than 25 years. In Florida alone, more than 19 million tonnes of phosphogypsum are disposed of annually using this method. The resulting gypsum stacks can reach heights greater than 30m.

A starter bund, using in the LTPS case decomposed granite, is first constructed to form a sedimentation pond and stacking area. Gypsum is pumped to the sedimentation pond in slurry form (thereby limiting the practical distance from the LTPS), usually at 15 to 20% solids and allowed to settle and drain to approximately 60 to 70% solids.



a) Typical Method of Gypsum Stack Construction



b) Typical Gypsum Stack Layout

Figure 5.3(a)

Gypsum Stack Construction and Layout

ERM Hong Kong
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

When sufficient gypsum sedimentation has taken place within the pond, the gypsum is excavated with a dragline or hydraulic excavator to raise the perimeter bund of the stack. The stacked gypsum is then shaped to form the crest of the bund using a bulldozer.

Slopes of the gypsum stacks as steep as 1:1.5 have been reported. The method of gypsum stack construction and typical gypsum stack layout are given in the site search study.

The required area of the gypsum stack is generally selected to allow raising the perimeter bunds approximately 1.5 to 2.4m per year. With respect to the potential gypsum production at the LTPS, the area required for the gypsum stack will be of the order of 10 hectares.

Erosion protection is not usually provided in the USA for the outside slope of the gypsum stack. Experience in the USA indicates that there is essentially no erosion of the slope from rainfall, and dusting has not been a significant problem. However, the extreme meteorological conditions in Hong Kong are severe and might require erosion protection on slopes of the gypsum stack. Hydroseeding of slopes would perform this function and provide a landscape feature. In order to hold topsoil cover and to provide access to maintenance equipment, slopes of 1:2.5 would be preferred from an engineering perspective.

(b) *Site Specific Considerations, Landfill Sites*

As for PFA land based disposal facilities, those for gypsum landfills was also limited to an area with 10km of the LTPS site due to economic and environmental considerations concerning transportation. Gypsum disposal related vehicle movements would amount to an estimated 150 per year by 2016 (*Scenario I*).

Potentially suitable landfill sites are as for PFA (ie. LF1, LF2 or LF4 – *Figure 3.3(a)*) either as dedicated gypsum facilities or with an area set aside for gypsum disposal. If developed, any of these landfills could accommodate all gypsum arisings.

The locations, characteristics, capacities and constraints to the use of these potential landfills were discussed at length in *Section 3.3.3* and hence the discussion here is confined to their suitability for gypsum in respect of availability, lifespan, economics and environmental impact.

(i) *Availability*

Landfill sites LF1, LF2 and LF4 are all wholly or partly within the Castle Peak Firing Range currently administered by HM Forces. These areas are reserved for firing practice until 1997 and use beyond 1997 is uncertain. However HM Forces have indicated early in the study they would not offer any site prior to 1997, but is now known to be considering a proposal from PAA to use a area encompassing LF1 and LF2 for a borrow area (see *Section 3.3*).

Unlike disposal of LTPS PFA where ash initially generated from the LTPS can be simply disposed of at Tsang Tsui Lagoons, new gypsum disposal facilities must be ready to accept gypsum by 1997 under *Scenario I*. Development of any landfill facility would need to be commenced in 1994, allowing 3 years for completion as per *Section 3.3*. Hence all identified landfills would not be available. Construction of temporary disposal facilities at Tsang Tsui or elsewhere for use until the year 2000 is not likely to be economic (see following sections).

In view of the above the following discussion applies to *Scenario II* firing only and remains subject to the availability after 1997 within sufficient time to receive gypsum in 2004 (i.e. planning to commence in 2001).

(ii) Capacities and Lifespans (Scenario II)

LF1 at 10 Mm^3 capacity, LF2 at 16 Mm^3 and LF4 at 55 Mm^3 could each absorb all gypsum arisings over the lifetime of the LTPS. At up to about 3 Mm^3 (4 Mte at a compacted density of 1400 kg/m^3 at 15% moisture) by 2016, total arisings under *Scenario II* would not warrant development of any of these sites for dedicated gypsum use. Hence, the only feasible utilisation of these landfills of gypsum disposal would be in a separate area of a site principally for the disposal of PFA. Since any PFA site will be designed to accommodate volumes about a factor of 10 greater than the gypsum arisings, it is concluded that suitability and ranking would not be significantly affected from those detailed in *Section 3.4* for *Scenario II*.

(iii) Economics

Relative disposal costs of gypsum are expected to follow those associated with PFA i.e. cost per tonne disposal will increase moving from landfills and quarries to marine lagoons except that use of an area in Tsang Tsui is likely to be more cost effective than developing an entirely new facility.

(iv) Environmental Issues

Aside from the gypsum specific issues addressed above, the environmental issues associated with LF1, LF2 and LF4 are as detailed in *Section 6.3.3(a)(iv) and (b)(iv)* to which the reader is referred.

(v) Recommendation

In terms of availability the identified landfill sites are not considered suitable for gypsum disposal under *Scenario I* firing.

If *Scenario II* were adopted the sites may be available (subject to removal or reduction in the size of the Castle Peak Firing Range), but their capacities are such that they could not be recommended as dedicated gypsum disposal facilities ahead of alternatives. However, if any of these sites were selected for ash disposal under *Scenario II*, it would be favourable to set aside at area for gypsum disposal, particularly were it for back-up purposes or for disposal of off-specification of gypsum as part of a buy-back arrangement.

(c) Site Specific Issues – Quarry Sites

Background information on the two identified quarry sites; Q1 at Lam Tei and Q2 at Tan Kwai; was given in *Section 3.3.4* in respect of location, capacity, constraints, economics and environmental issues these apply equally for gypsum disposal as do the general considerations discussed above.

(i) Capacity and Lifespan

At a capacity of 5 Mm^3 and 4 Mm^3 quarries Q1 and Q2 would not provide adequate space for the estimated 5.7 Mm^3 (8 Mte) of gypsum produced under the high growth conditions by 2016 with *Scenario I* firing. However, with average or low growth in electricity demand either site would probably accommodate all arisings as shown in *Table 5.3(a)*.

Table 5.3(a)
Quarry sites, capacity and gypsum lifespans

		Lifespan	
Quarry Site	**Capacity** (Mm^3)	**Scenario I** (until)	**Scenario II** (until)
Q1 Lam Tei	5	2017	2025
Q2 Tam Kwai	4	2015	2021

Note: Lifespans from given dates refer to those from when arisings begin assuming no utilisation, average growth in electricity demand and burning of 16% ash content coal.

Table 5.3(a) also shows lifespans under *Scenario II* indicates that all arisings could be placed in either quarry over the first 20 years of LTPS operation.

(ii) Constraints

Under *Scenario II* the sites may suit PFA disposal (*Section 3.3.4*) or, under either scenario, disposal of FBA (*Section 4.3.1(e)*). In addition:

- Quarry Q1 may not be available until 2005 unless GEO restrict any reviewed licence for further quarrying.
- Quarry Q2 would need to be acquired from the administration of DLO.

(iii) Economics

Disposal in one of these quarry sites is likely to be comparable to one of the landfill sites.

(iv) *Environmental*

No significant environmental impact should result given design and operation in accordance with the principles stated above (*Section 5.3.3(a) & (b)*) and in *Section 3.3.4*. Placement would be in 'dry' conditioned form at 15–20% moisture. Benefits would be afforded by restoration of the quarry sites (c.f. the likely visual intrusion/land–use sterilisation of landfill options). Any leachates would most likely pass to sewer since it would be more difficult to transport these back to the LTPS due to the greater distance that at landfills. Any impacts of the transport operations for gypsum would be increased over those at landfill sites due to the extra kilometres and the need to pass through populated areas.

(v) *Recommendation*

In the event that disposal at sea of gypsum product is neither technically feasible nor environmentally acceptable (see *Section 5.3.4* below) disposal of gypsum arisings or off–specification product to Q2 (preferred for *Scenario I or II*) or Q1 (when available) appears a feasible and attractive disposal option. Such a facility would also afford back–up capacity in the event of failure of any export arrangement. The two quarries may form a useful combined strategy if planned sequentially as back–up facilities for both FGD gypsum and FBA under either scenario.

5.3.4 *Disposal at Sea*

(a) *Dissolution in Seawater*

Since gypsum is soluble in water it is theoretically possible to dissolve it in the power station's cooling water and discharge the resulting solution to sea. Seemingly the most practical way of affecting this is not to dewater the gypsum in the first place. The bleed stream from the absorber (a saturated calcium sulphate solution containing suspended fine gypsum crystals) could simply be diverted to the cooling water channel after primary thickening. A proportion could be passed to a water treatment plant to extract part of the toxic metal load.

The above process configuration falls in between the conventional gypsum producing plants and the seawater FGD systems. In the Bechtel process a seawater/lime reagent produces a product stream of gypsum saturated seawater, whilst in the Flakt process the gypsum is kept in solution by the use of larger quantities of seawater reagent and vast aeration ponds. These systems do away with the need for towns water by utilising seawater. The systems also reduce the quantity of reagent required since seawater is itself alkaline with a buffer capacity to absorb acidic SO_2 emissions.

The viability of all the 'dissolution' options depends not only on proving their technical feasibility (none have yet been demonstrated on a commercial scale) but also upon the impacts to the marine environment at and around the point of discharge. There are three areas of key environmental concern.

- *Sedimentation*: Suspended solids in the effluent may result from a number of factors:

  - incomplete dissolution of suspended gypsum crystals at the discharge point, i.e. the system needs to be designed to produce fine crystals so that these can completely dissolve in the short time it takes to pass from the absorbers to the discharge point – a process that depends on the solubility rate of gypsum (rather than its limiting solubility at seawater pH);

  - inert insoluble constituents in the lime or limestone reagent, up to 5% by weight – equivalent to up to 400 kg/hr/unit (20,000 te/yr assuming 50,000 operating hours) of solids discharged (*Scenario I*) or 5.3 mg/l in the cooling water;

  - entrainment by the scrubbing fluid of small insoluble PFA particles in the flue gas not captured by the electrostatic precipitators (which should capture in excess of 99.7% of PFA emanating from the boiler). If there were no prescrubber fitted this could amount to over 70 kg/hr/unit (3,500 te/yr Scenario I) being discharged with the cooling water equivalent to raised suspended solids of 1 mg/l at the outfall discharge.

  Experience in the Humber estuary and Avonmouth by ICI with a much more concentrated gypsum slurry than would be the case at the LTPS outfall, showed that where there are strong tidal currents sedimentation should not occur. Urmston Road, wherein the LTPS outfalls will be located, is subject to rapid tidal currents associated with the Pearl River. Suspended solids in the outfall should disperse without leading to sedimentation.

- *Visible Plume* (milky white) on the surface in the proximity of the discharge point would result if gypsum crystals were not fully dissolved on exit from the outfall. Manufacturers of the Seawater FGD systems claim that all gypsum would be in solution on discharge, however although this has been shown on pilot plant, no such system has yet been commercially demonstrated. Assuming dissolution of gypsum raised levels of suspended solids due to the FGD (i.e. ash and inerts) are such that a plume should not be visible.

- *Discharge of dissolved toxic metals*: The limestone reagent, feed coal (hence the PFA) and towns water all contain quantities of toxic metals, although in trace amounts. In the standard configuration the limestone/gypsum process outputs these metals in the product gypsum and in the purge stream. However, in the dissolution configuration or with Seawater FGD all metals that would have been in the gypsum are discharged to sea – some trapped within the matrix of insoluble particles, but a considerable proportion in dissolved form. The potential impacts of this metal load are assessed in the parallel *Water Quality KIA*[5]. That assessment has modelled the dispersion and accumulation in sediments of representative metals and found that no significant adverse effects are likely to acrue.

The impacts of raised calcium and sulphate ion concentrations from background levels of 350 and 2,100 mg/l[57] by 42 and 103 mg/l respectively are not considered significant in themselves since levels will rapidly approach those of the surrounding seawater on discharge. Neither species are harmful to marine organisms at the levels specified (see the Water Quality KIR[5]).

Recommendation

With the outcome of the Water Quality KIA and the adverse environmental impacts that will inevitably result from on-land disposal of gypsum, all be it of limited significance, the Consultants recommend that CLP pursue the dissolution configuration and the Seawater Systems to ascertain their technical feasibility, both in theory and if possible with a trial demonstration. All practical, cost-effective, means to mitigate the potential environmental concerns discussed above should however be instituted to minimise any impacts.

(b) *Marine Dumping*

As an alternative to land based disposal options, all of which have constraints to their use that would need to be resolved, or the dissolution option, product gypsum might be dumped at sea, either within Hong Kong Waters or in International Waters. The possible options associated with marine dumping where discussed in *Section 3.3.5* in the context of PFA (in respect of location, capacity and economics) and apply equally to gypsum dumping.

Unlike PFA, gypsum is not the subject of a specific prohibition regulation and might feasibly be deposited at a Gazetted Marine Dumping Area or Reduntant Marine Borrow Area in Hong Kong or alternatively it could be dumped in international waters. EPD's "Waste Disposal Plan For Hong Kong"[21] addressed the issue of dumping at sea and concluded sea dumping is suitable only for the disposal of:

> "(a) *material that sinks, is non-toxic and will not present a hazard to shipping*
>
> (b) *material that is non-toxic and will dissolve and disperse readily in sea water"*

Unlike PFA the volume produced is much reduced (at about 15% of total CLP PFA production in 2016 and it is also soluble, all be it sparingly. Hence over time gypsum dumped (and not covered) would gradually dissolve. The rate at which this would occur would depend upon the particle size, degree of compaction when dumped, thickness of dumped layers and local marine conditions - currents, pH, concentration of calcium and sulphate ions etc.

FGD gypsum is not classified as a toxic waste in Europe, Japan or the USA and is unlikely to be so classified in Hong Kong although it does contain trace amounts of toxic metals, much of which would dissolve along with the gypsum.

Adverse environmental impacts could result from effects to marine ecosystems arising from sterilisation of the seabed, leaching and dissolution of toxic metals. These effects would also be site specific and vary according to the factors affecting the rate of dissolution.

(57) CLP Background Water Quality Monitoring, Black Point, (October 1990 - August 1991) - mean values.

Marine dumping of solid gypsum would also be energy intensive relative to dissolution. Dewatering the slurry exiting the absorber, requires the use of capital intensive processing equipment that consumes significant amounts of power station electrical output. The dewatered gypsum would then need to be stored to await transfer to barges, which would then travel to the dump site. The net result would not be as satisfactory as the dissolution option, but has the advantage of being a proven technology. The method may result in more significant localised accumulation of toxic metals on the seabed that the dissolution option.

An alternative might be to stabilise the gypsum by addition of PFA, lime, and possibly cement and/or wastewater treatment sludge (see *Section 6*). This mixture would form hard leachate resistant blocks that might be used to enhance the marine environment via construction of an artificial reef as described in *Section 5.2.5*.

(i) Recommendation

Marine dumping of gypsum would, at least temporarily, take up valuable space in gazetted dump sites or borrow areas and would not enable gypsum to be reclaimed for later use. In addition, disposal in Hong Kong or International Waters is an inefficient means of disposal in comparison to the Seawater FGD systems and dissolution Limestone/Gypsum FGD system options, if these where shown to be technically feasible.

The Consultants would recommend that marine dumping is only pursued when, and if, it is shown that the alternative 'disposal at sea' options are impracticable.

5.4 *INTEGRATED 20 YEAR MANAGEMENT STRATEGIES*

5.4.1 *Introduction*

Sections 5.2 indicated that whilst several options for FGD gypsum utilisation exist none can be relied upon to actually consume LTPS gypsum locally at this time. Export might however be feasible. Disposal is thus of importance to the more immediate question of what disposal route should be adopted for LTPS gypsum arisings.

5.4.2 *Beneficial Utilisation of FGD Gypsum*

Five options for the beneficial utilisation of gypsum have been reviewed:

- *Wallboard Manufacture*: Could potentially utilise most of the gypsum arisings from the LTPS (90%, upto 10% would be off-specification and not suitable for wallboard), but market outlets do not exist locally and capital for a plant would be a major obstacle.

- *Cement Manufacture*: Up to 100,000 te/yr could be utilised at CCCs kiln (1 LTPS unit output), but technical constraints to this use would have to be overcome.

- *Fill Material*: Use as fill would require the feasibility to be demonstrated and whilst of long term potential, is considered an inappropriate strategy at a time when PFA is yet to be fully accepted as a fill material.

- *Artificial Reef Construction*: Also of long term, rather than immediate potential since trials are just beginning with artificial reefs made of PFA concrete. However, it is likely that trials of several years duration would be required before it can be concluded if FGD gypsum is a suitable reef material in Hong Kong.

- *Export*: Via a 'buy--back' arrangement with a limestone supplier (similar to that arranged by HEC) could utilise 90% of FGD gypsum arisings. (upto 10% would be off--specification product requiring disposal). However, due to technical constraints to the FGD system, security and economic issues the option cannot be relied upon entirely.

In the light of the above the only utilisation rate that can be quantified is the *potential utilisation* of 90% resulting from export, which, if maintained for the 20 year period would reduce arisings requiring disposal from 6.6 Mte to 0.6 Mte - *Scenario I*, average growth - or from 3.7 to 0.4 Mte - *Scenario II.*

5.4.3 *Disposal of FGD Gypsum*

Disposal routes for all FGD gypsum arisings would be required regardless of whether or not an export arrangement were completed, to afford back-up in the event of failure.

Again all disposal options identified would require the resolution of certain constraints. The situation were *Scenario I* firing adopted is particularly critical since arisings would begin in 1996 implying detailed planning must commence in 1993, well before that for any further, ash disposal facility.

Since gypsum is a soluble material, disposal at sea, via direct absorption of SO_2 into seawater or dissolution of the gypsum in seawater is the preferred disposal route, *provided* water quality impacts are not determined to be unacceptable (refer to the Water Quality KIR[(5)]). This refers to both firing Scenario's, but adoption of this option would also require technical constraints on the use of Seawater FGD or dissolution to be resolved.

Marine dumping of solid product may be feasible, but is considered to be an inefficient means of accomplishing disposal at sea and is potentially of greater environmental concern than the above.

Landfill sites identified in the study would not be suitable to *Scenario I* since they would not be available prior to 1997 (a separate area at Tsang Tsui could possibly act as a temporary storage or small permanent disposal site in the worst case). For *Scenario II* quantities requiring disposal would only suit development of part of a landfill site - the remainder of the capacity could be devoted to ash disposal, although PFA lifespans would reduce slightly.

Either quarry site could probably accommodate all LTPS gypsum arisings during the first 20 years of operation under either *Scenarios I & II.*

Disposal routes for LTPS FGD gypsum are thus ranked as follows (for *Scenarios I and II* except where stated).

1) Disposal at Sea

   (i) Seawater FGD
   (ii) Dissolution of Gypsum arisings from Limestone/Gypsum FGD
   (iii) Marine Dumping in Hong Kong or International Waters

2) Separate area at PFA Landfill (*Scenario II* only)

3) Quarry site Q1 or Q2

4) Temporary use of a separate area a Tsang Tsui (*Scenario I*)

Before any of these disposal routes could be enacted constraints given in *Section 3.4.3, Table 3.4(b)* and *Section 5.3* would require resolution in respect of the feasibility of disposal at sea and availability of disposal sites.

5.4.4 Gypsum 20 Year Management Strategy

The aim of the gypsum management strategy must be to focus on selecting and confirming the suitability of a disposal facility (back-up or otherwise) once firing scenario is selected.

(a) Beneficial Utilisation of Gypsum

If coal is to be burnt at the LTPS and a solid gypsum producing FGD system is installed, then efforts will be needed to encourage the beneficial utilisation of gypsum by both CLP and Government if the problems associated with waste disposal are to be avoided. Strategic actions specific to gypsum utilisation, once firing option is decided are summarised in *Table 5.4(a)*.

Table 5.4(a)
FGD Gypsum Utilisation Strategy - Actions

China Light & Power Company	Government
Export	
• Negotiate a "buy-back" arrangement if possible and secure back-up disposal facilities. If export is not possible then proceed as below.	
Wallboard Manufacture	
• Investigate potential markets and economic viability, consider subsidies	• Encourage changes in building practice to favour wallboard over imported plywood.
Cement Manufacture	
• Investigate technical constraints to use and market to CCC accordingly.	
Fill Material	
• Commence trials and tests once PFA is fully accepted as a fill material.	
Artificial Reefs	
• If PFA concrete reefs prove successful, market the use of FGD gypsum with PFA concrete in subsequent projects.	

(b) Disposal

Dates at which detailed planning for new facilities should commence are 1993 for *Scenario I* and during 2001 under *Scenario II*, allowing three years for planning and construction.

Table 5.4(b) summarises recommended strategic actions to be taken once firing option is decided.

Table 5.4(b) *FGD Gypsum Disposal Strategy – Actions*	
China Light & Power Company	**Government**
Disposal at Sea • Investigate constraints to use of Seawater FGD, gypsum dissolution and, if unsuccessful, marine dumping. *Landfill* • Incorporate provision for separate gypsum disposal area in licence application for any PFA landfills (*Scenario II*). • Quarries Apply for licence.	
See also *Table 3.4(b)*	

6. WASTEWATER TREATMENT SLUDGE (WTS) MANAGEMENT

6.1 INTRODUCTION

The wastewater treatment sludge arises from treatment of the purge water bled from the Limestone/Gypsum FGD system to control the build up of soluble salts including chloride and other contaminants in the system. The purge stream is typically taken from the gypsum dewatering plant. Treatment of the effluent is needed prior to discharge in respect of the TM[46] solids concentration, dissolved metals, and COD, so it is passed on for wastewater treatment. After treatment, wastewater is discharged to sea.

Note, it is likely that sludge would only arise if the Limestone/Gypsum FGD system were adopted. Seawater FGD does not require a purge stream to maintain the scrubbing conditions since any contaminants are withdrawn with the dissolved gypsum.

Actual arisings of WTS will depend on the specifications of the feed coal, limestone reagent and process water in addition to the particular process design. Likely worst case arisings would be about 65 kte/yr, or a cumulative quantity of 770 kte in 2016 assuming *Scenario I* firing. Quantities under *Scenario II* would be half those for *Scenario I*. In addition HEC could be producing up to 15 kte/yr, amounting to about 350 kte in 2016.

Even if the Limestone/Gypsum system is selected there are potential options that could avoid the production of sludges or reduce the volume significantly[3],[17]:

- *Recycling of the sludge to the furnace*: This method has successfully been carried out in the Netherlands where sludge is injected into the furnace with the coal. Initial concerns expressed at the possible revolatisation of the contaminants proved groundless.

- *Recycling of the sludge to the FGD Process*: Some German plants (e.g. Heilbronn) have used this method, whereby sludge is partially dewatered and collected in a holding tank. Periodically the sludge is recycled through the FGD process. The implication is that much of the gypsum and metals in the sludge are diluted in the product gypsum, altering its specification slightly.

- *Mitsubishi Wastewater Evaporation System (WES)*[58]: This system has been successfully used in Japan and the manufacturers claim superior economics over traditional wastewater treatment. Wastewater from the FGD system is first neutralised and then sprayed under pressure in the flue gas duct to vaporise the wastewater. Impurities in suspension and dissolved in the wastewater are dried to solids by the heat of the flue gases and then removed with the PFA in the ESP. This system removes both the need to dispose of a solid sludge and wastewater stream.

However, these systems have not been widely proven to be commercially viable as yet. It would be necessary to show there are no adverse effect on downstream components.

(58) Mitisubishi Heavy Industries, Ltd, (1991) *"Technical Information of Mitsubishi Wet Flue Gas Desulphurisation System"*

- *Wastewater as FBA quench or PFA conditioner*: Either activity would effectively remove the issue of sludge generation. However, neither is known to have been used elsewhere and adequate demonstration would be required to show the diluted contaminants would not present problems in any FBA or PFA utilisation or disposal strategies. Sludge, if disposed of with PFA would be diluted by about 20 fold by the mixing process.

- *Sludge Reduction*: The water treatment process for FGD effluents typically relies on neutralisation and desaturation followed by staged sedimentation and sludge dewatering. The effluent is initially supersaturated with gypsum and needs to be desaturated as much as possible before the metals treatment stages. Lime solution added in the first stage allows simultaneous neutralisation and desaturation. After addition of flocculant, most of the solids can be separated (these would consist of mainly gypsum, entrained PFA, silicates, carbonates, fluorides, phosphates and some metals). This portion of the sludge could be dewatered separately and would be of much lower toxicity than if combined with second stage sludges. In the second stage, reagents such as ferric chloride and flocculants are added to remove residual heavy metals as sedimented solids. It is quite possible that upwards of 80% of sludge volume could be collected in the first stage, leaving only a small portion containing toxic contaminants at raised levels. The vast bulk could then be simply mixed and disposed of with gypsum whilst only the remainder undergoes further treatment.

If WTS does arise it will not be suitable for direct utilisation since it will contain raised levels of certain toxic metals and has a relatively high Chemical Oxygen Demand (COD). Hence, an indirect utilisation or disposal route will be required.

6.2 *UTILISATION OF WTS*

6.2.1 *The Options*

Potential utilisation options for WTS involve dilution with other by-products from the LTPS and/or added reagents. The options considered below are taken from those considered for PFA or Gypsum. The WTS could potentially be incorporated without altering the properties of the material significantly. As the main environmental concern with the sludge centres on potential impact to water quality via the leaching of contaminants from the sludge, the study has concentrated on options that will lock these species in a cementitious matrix. Potential utilisation options are the following:

- *Manufacture of Lightweight Aggregates or Autoclaved Aerated Concrete Blocks (AACBs)*: PFA could be used to manufacture these products (see *Sections 3.2.4 and 3.2.5*), and it would seem that there would be few additional concerns if FGD wastewater conditioned PFA or a sludge/PFA mix were substituted in the process as contaminants would be locked in a cementitious matrix. However, cement used in AACB manufacturing might need to be sulphate resisting (depending on the proportion of sludge). Otherwise it may degrade and cease to act as an effective binder.

- *Manufacture of FBA Concrete Blocks*: This is a similar to the AACB option above except that FBA is used. It would need to be demonstrated that block properties and the manufacturing process is not affected and current block makers would need to accept FBA treated with sludge (see also *Section 4.2.2*).

- *Artificial Reef Construction*: As discussed in *Section 5.2* artificial reefs comprising PFA, cement, FGD gypsum and sludge have been tested in the UK and US. Environmental benefits to marine ecology have been demonstrated and neither leaching of metals nor toxic metal bioaccumulation in marine life has occurred to appreciable effect.

- *Reclamation Material*: PFA or a PFA/Gypsum mix conditioned with untreated FGD wastewater may be suitable as a reclamation material if it can be demonstrated that there is no detectable deterioration in the leachate from the material. This is of long–term rather than immediate potential since PFA is not yet fully accepted as a reclamation fill.

- *N–Viro Process:* As discussed in *Section 3.2.8* WTS might be a potential ingredient in the manufacture of N–Viro Soil for use as interleaving material. Concerns over the availability of WTS sulphate content would need to be alleviated if production of toxic H_2S is to be dismissed as an issue.

None of these options can be relied upon as a management strategy at this time for reasons given above or in the referenced sections. However, given appropriate research on behalf of CLP it would appear that there is scope for any sludge arisings to be beneficially utilised, depending on the utilisation option pursued for other by–products.

6.3 DISPOSAL OF WTS

6.3.1 The Options

As with gypsum, protection of marine and aquatic water quality would be the prime consideration in the determination of the optimum disposal route. The range of disposal options is also dependent on the management options selected for other by–products. The composition of the sludge from FGD effluent treatment plants is such that in relation to the UK's Special Waste Regulation and probably in relation to USEPA toxicity tests (although there is insufficient data to test against all sensitive species) the sludge would not be classified as a 'special' or 'hazardous' waste respectively. It could be classified as a chemical waste in Hong Kong due to its metal content. In the light of this situation the following disposal options are considered.

- Codisposal with gypsum or fuel ash.

- Dewatering and disposal within a separate, controlled area of PFA or gypsum facility.

- Sludge stabilisation and subsequent disposal.

- Disposal by others.

6.3.2 *Codisposal*

If gypsum is destined for disposal then codisposal could be considered. Whilst co-utilisation with ash has been considered, codisposal is less likely to be favoured since this may disqualify PFA or FBA from later harvesting and utilisation. However, as with the potential utilisation options discussed above, this condition could be waived if it could be shown that dilution of ash with sludge does not alter the chemical and physical characterisations of the ash. Hence, the Consultants would recommend that CLP initiate appropriate testing were sludge to be produced.

6.3.3 *Dewatering and Separate Disposal*

When dewatered to 25% dry solids content, the sludge behaves as a dry cake and would be in a suitable form for trucking to land disposal sites. This is practiced in Europe, for example at Voerde TPS in Germany. It is not considered viable to dedicate a particular site to WTS and use of a municipal landfill would not be appropriate for dewatered sludge.

Disposal in a separate area within a gypsum or ash disposal site could be considered. The area would need to be contained and any leachate and runoff would require treatment prior to discharge from the site. If a leachate treatment plant were incorporated into the design of a landfill for gypsum then this form of disposal may be considered.

6.3.4 *Stabilisation and Disposal*

Cement or a PFA and lime admixture could be mixed with the sludge to bind it chemically and physically prior to placement in a disposal facility. Such a process could effectively render the sludge in an environmentally benign form in respect of potential impact to the aquatic environment. The process is essentially similar to that proposed for artificial reef concrete blocks.

Typically about 50 parts sludge would be mixed with 20–30 parts PFA and 20–30 parts lime or cement to form the stabilised mixture[59]. Such a facility could be incorporated into the design of the LTPS FGD plant and could be employed to stabilise at least the toxic metal portion of any sludge generated. Disposal could then be to separate area within a by-product disposal facility or potentially, to a municipal landfill if permitted.

6.3.5 *Disposal By Others*

The Chemical Waste Treatment Facility (CWTF), currently being constructed on Tsing Yi Island, incorporates a waste stabilisation plant similar to that proposed above. This plant is intended to treat up to 65 te/day of sludges of various kinds and considerably more toxic than the FGD WTS. The process, which will operate on a commercial basis, is cement stabilisation incorporating ash from the CWTF waste incinerator. The estimated 160 te/day output from the stabilisation plant is destined for the SENT municipal landfill.

(59) Stephanatos, B.N., MacGregor, A. *"Stabilisation and Delisting of Hazardous Wastes"* HMCRI's Hazardous Materials Control '91, Washington D.C. (December 1991).

Estimated sludge production at both utilities (CLP & HEC) could amount to between 110 and 220 te/day, depending on process configuration and firing scenario. This is clearly in excess of the capacity at CWTF. However, if sludge reduction could be incorporated, as suggested in *Section 6.1*, then quantities would only amount to between 24–45 te/day and could be handled at CWTF.

The Consultants do not favour such a strategy since this goes against the primary reason for the development of the CWTF, which is intended to treat waste from smaller industries who would otherwise find the costs of waste treatment onerous to the economic viability of their processes. The electricity utilities might be better served by treating their wastes on site, utilising their own ash in the stabilisation process.

Under *Scenario I* CLP could utilise up to 35 kte/yr of PFA in a WTS stabilisation plant.

6.4 INTEGRATED 20 YEAR MANAGEMENT STRATEGIES

6.4.1 Introduction

The proceeding sections indicate that there are various options that may result in no wastewater treatment sludge being produced at all via:

- Use of Seawater FGD
- Recirculation:
  - of the sludge to the furnace;
  - of the sludge to the FGD process;
  - of the untreated effluent to the flue gases (the WES system).
- Wastewater as FBA quench or PFA Conditioner.

If WTS were produced it might be possible to substantially reduce the quantity requiring special handling via separation of the inert solids and toxic contaminants in the effluent treatment plant.

6.4.2 Beneficial Utilisation of WTS

Several options have potential to utilise all sludge arisings in combination with the utilisation of other by-products, namely as:

- Reclamation Material with PFA or PFA/Gypsum;
- Manufacture of Lightweight Aggregate or Autoclaved Aerated Concrete Blocks (AACBs) with PFA;
- Manufacture of FBA Concrete Blocks;
- Artificial Reef Construction with PFA or PFA/Gypsum.

However, none of the above can be relied upon as a secure management strategy at this time.

6.4.3 *Disposal of WTS*

Potential disposal options are linked closely with those for FGD gypsum, since in most instances it would be preferable to dispose of WTS in separate areas of any FGD gypsum disposal facility. Alternatively, the sludge might simply be dispersed amongst any gypsum destined for disposal, since gypsum cannot readily be stored for possible later harvesting and utilisation.

Sludge disposal would either be in the form of a filter cake or stabilised cementitious material, dependent upon the outcome of future study into the sludge properties and whether a leachate treatment facility were installed at the gypsum disposal facility.

Disposal via CWTF is only feasible if the inert and environmentally sensitive constituents of WTS could be separated during effluent treatment, but this would only be recommended as a last resort.

The ranking of disposal sites follows that determined for FGD gypsum (see *Section 5.4.3*).

6.4.4 *WTS 20 Year Management Strategy*

The management strategy follows that for FGD gypsum in that prevention of arisings is preferred to development of utilisation options, which is in turn preferable to disposal. However, if WTS does arise then the strategy must afford a disposal route acceptable on environmental grounds.

(a) Beneficial Utilisation of WTS

If WTS does arise, efforts would be required by CLP to determine the acceptability of potential utilisation options. Strategic actions specific to WTS utilisation, once arisings are confirmed are summarised in *Table 6.4(a)* (see also *Table 5.4(a)*)

Table 6.4(a)
WTS Utilisation Strategy - Actions

China Light & Power Company	Government
Fill Material ● Commence trials and tests with gypsum once PFA is accepted as a fill material ● *Lightweight Aggregates and AACBs* Investigate technical feasibility and economic viability ● *FBA Concrete Blocks* As above ● *Artificial Reefs* If PFA concrete proves successful, market the use of FGD gypsum and WTS in subsequent projects	

(b) Disposal

Dates at which detailed planning for the disposal route (with gypsum) would be immediately under *Scenario I* and during 2000 for *Scenario II*, allowing one year for feasibility determination and three years for planning and construction.

Necessary actions are as outline in *Table 5.4(b), Section 5.4.*

7. *SUMMARY, CONCLUSIONS AND RECOMMENDATIONS*

7.1 *INTRODUCTION*

The aim of this study has been to first quantify and then examine in respect of technical practicality, economic feasibility and environmental impact the practical options for the utilisation or disposal of thermal power station by-product arisings over a twenty year period of operation of the proposed LTPS at Black Point. The study has encompassed arisings from Castle Peak and the LTPS at Black Point. HEC by-product arisings have also been considered where appropriate.

7.1.1 *Arisings*

The study has accounted for two principal potential firing options at the LTPS:

- *Scenario I*, entailing 8 coal-fired units fitted with flue gas desulphurisation (FGD), in accordance with the 'Best Practical Means' concept for the abatement of stack emissions. By 2016 by-product arisings from LTPS and CPPS under the 'worst case' conditions would comprise the following:

  - PFA: 54 Mte at a rate of 3.2 Mte/yr;
  - FBA: 6 Mte at a rate of 350 kte/yr;
  - FGD gypsum: 8.5 Mte at a rate of 710 kte/yr;
  - Wastewater Treatment Sludge (WTS) 770 kte at a rate of 65 kte/yr.

- *Scenario II*, where the first four units would be CCGTs fired on natural gas, giving rise to no significant solid by-product arisings. The remaining four units would be coal-fired, producing the following in the 'worst case' situation by 2016.

  - PFA: 42 Mte at a rate of 2.3 Mte/yr
  - FBA: 4.7 Mte at a rate of 250 kte/yr
  - FGD gypsum: 4 Mte at a rate of 350 kte/yr
  - Wastewater Treatment Sludge (WTS): 370 kte at a rate of 32.5 kte/yr

The FGD Plant could also consume large quantities of Towns Water, upto 64 Mm^3 and 30 Mm^3 for *Scenarios I and II* respectively. Note however that CLP are considering the feasibility of using seawater as an alternative.

Periodic use of heavy fuel oil may be made by CLP. During such periods, arisings of ash would be virtually eliminated, but quantities of gypsum from the FGD plant could increase by upto a factor of 2.

The figures given above have been calculated on the most pessimistic basis, but are nevertheless substantial, and commensurate with what could be one of the world's largest coal-fired power plants. Implications to the environment of Hong Kong would be equally substantial in respect of the size of disposal facilities required were all arisings to be disposed of, particularly in respect of ash.

Arisings of FGD gypsum and WTS, if realised, would be as a direct result of the abatement of potentially harmful gaseous emissions of SO_2. Hence, the relative impact of the disposal of these by-products to land or marine environments is of concern, otherwise potential air quality impact may be transferred to impacts on other media.

7.1.2 *Beneficial Utilisation*

In line with the findings of the Government's *Waste Disposal Plan for Hong Kong*[21], the Consultants have first assessed the by-products as prospective resources that could be usefully employed by the Territory as a whole.

Environmental benefits of utilisation include;

- the elimination of a significant quantity of material requiring disposal;
- the elimination of environmental aspects associated with the production and supply of conventional materials.

This has been conducted both within the current market conditions and regulatory framework and under foreseeable and practical future situations. Where appropriate and feasible, potential utilisation has been quantified.

For each utilisation option identified the Consultants have assessed:

- Economic and technical constraints and benefits;
- Environmental impacts and benefits;
- Present and future market potential.

On the basis of the assessment, suitable strategies are suggested to maintain and/or realise beneficial utilisation. In general, steady continuous commercial outlets for by-products are preferred over intermittent uses, since there would be less need for storage. Recommendations regarding necessary actions by the utility or Government are put forward.

7.1.3 *Disposal*

Quantities of by-products that cannot be beneficially utilised will require disposal. It is also essential that suitable disposal facilities are identified to afford adequate back-up capacity for all arisings if present or future utilisation were to fail. A site search was initiated by CLP to identify possible disposal sites within a reasonable distance of their TPSs. These sites have been assessed on a preliminary basis in terms of their engineering, environmental and economic feasibility for disposal of specific by-products. Major practical or regulatory constraints to the use of these sites have been investigated and appropriate recommendations made.

Disposal of large quantities of solid by-products at sea, in dedicated landfills or lagoons will inevitably incur some level of environmental impact, via visual intrusion, deterioration of air or water quality and/or the sterilisation of the seabed or inland areas. Hence, it is desirable that development of any new facilities proceeds only when they are required and that efforts are made continually by all concerned parties to utilise by-products beneficially elsewhere. Utilisation will also yield economic benefit in the form of the saved costs of disposal and of the material the by-product displaces.

The Consultants have recommended various strategic actions that would need to be undertaken by CLP or Government and forecast when detailed planning would need to commence under the various firing and operational scenarios. For each by-product the suitable disposal routes have been ranked on the basis of the material specific assessments.

The site search identified the following sites as potential LTPS disposal facilities in addition to the remaining capacity at Tsang Tsui Ash Lagoons (see *Figure 3.3(a)* and *Annex D*):

- *Marine Lagoons*
  - Extension of the capacity and working life of the existing lagoons at Tsang Tsui;
  - ML1 and ML2, comprising the proposed Tuen Mun Port Development reclamation area;
  - ML3 and ML4, to the north east of the existing lagoons at Tsang Tsui.

- *Landfills*
  - LF1 and LF2, adjacent valley sites within 1 km, to the north of CPPS in the Castle Peak Firing Range;
  - LF4, a very large valley site, also within the Firing Range, to the north east of Ha Pak Nai;

- *Quarries*
  - Q1, Lam Tei Quarry, lies immediately to the east of Lam Tei;
  - Quarry Q2 is situated about 0.5km to the north east of Q1 at Tan Kwai.

The preliminary assessment of these potential facilities has established their engineering feasibility and estimated their economic viability and capacities.

However, practical constraints to the use of all the potential sites have been identified. The resolution of these constraints would require actions from Government. *Table 7.1(a)* summaries the issues.

The study has not been restricted just to these particular fixed sites, but has also investigated:

- *Disposal At Sea*
  - In Hong Kong Waters (at gazetted dumping grounds or unfilled marine sand borrow areas);
  - In International Waters.

Table 7.1(a)
Potential Disposal Facilities Summary

Disposal Facility	Capacity (Mm³)	Economic Issues[1]		Likely Environmental Acceptability[3]	Constraints to Development	Government Actions
		Relative Cost/te	Rank			
Tsang Tsui	5.5	Very low	1	Acceptable	–	–
Tsang Tsui Extended	13	Low	2	Acceptable	a. BBC Radio Station b. TMP Development proposed for 2011	a. Alteration of Letter of Intent b. Deferment of proposed TMP Development
ML1 + ML2	17	High (Low[2])	8	Acceptable	a. TMP Development proposed 1996–2011	–
ML3 + ML4	10	Very High	9	Poor	a. Located in Mariculture Zone	–
LF1	10	Moderate	7	Acceptable	a. Located in Firing Range	a. Approval of Firing Range use
LF2	16	Moderate	3	Acceptable	a. Located in Firing Range	a. as above
LF4	55	Moderate	6	Possible	a. Located in Firing Range b. Possible need to relocate villagers	a. as above
Q1	5	Moderate	4	Acceptable	a. Quarry still active	a. GEO limiting quarry licence from 1992
Q2	4	Moderate	4	Acceptable	a. Currently contractors depot	a. DLO to approve change of use

1 Given as broad estimates of relative costs, ranks in order of ascending cost per tonne, disposal including land acquisition, construction and operation. Incremental costs are given for Tsang Tsui.
2 Based on use as soft fill into reclamations constructed by others.
3 Given institution of recommended mitigation measures and satisfactory completion of a detailed EIA

- *Codisposal*:
  - of ash or FGD by-products;
  - of ash and FGD by-products.
- *Use of Underground Caverns at Yuen Long*

7.1.4 *Integrated 20 Year Management Strategies*

For each by-product the feasible management options have been compiled into long term strategies.

The quantities of by-product that can be consumed beneficially under both current and foreseeable conditions were estimated. Necessary strategic actions on behalf of CLP and/or Government to maintain and/or increase utilisation have been recommended. The Consultants believe that institution of these recommendations will result in lowering the quantity of by-products requiring disposal significantly, or possibly entirely. Only those utilisation options that have been shown to be environmentally acceptable and economically justifiable have been pursued.

The study has identified many utilisation options that appear to have considerable long-term potential, but in the foreseeable future it is not possible to quantify with any certainty the amount of by-product that could be consumed. These options have not been included in the forecast utilisation rates, but might significantly add to the amount of by-products utilised, particularly in the later years of operation.

The quantified utilisation rates have been used together with the assessments of the various potential disposal facilities to rank sites that could accommodate all arisings over, at least, a 20 year period of LTPS operation. The ranking covers both the most pessimistic situation, where a secure disposal route is required for all, or almost all, arisings, and under the foreseeable utilisation rates. As such, a hierarchy of strategies are available to the utility. For example, if the constraints to the use of the preferred disposal route cannot be resolved, the attention can shift to the facility next in line. The adopted strategies give planning dates when the constraints would need to be resolved. Being some way off, they offer time for this process to be completed, in addition to allowing time for utilisation markets to develop.

7.2 PULVERISED FUEL ASH (PFA) MANAGEMENT STRATEGY

7.2.1 Introduction

PFA originates from the ash contained within the coal fed to the furnaces. It is carried out with the flue gases and collected at an efficiency in excess of 99.5% in electrostatic precipitators (ESPs) prior to the FGD system. CLP could be producing up to 3.2 Mte/yr in 2016, whilst HEC would add about 0.65 Mte/yr, cumulative totals of 54 Mte and 12 Mte respectively.

Current CLP PFA produced at CPPS is mostly disposed of at Tsang Tsui ash lagoons. However, between 0.3–0.4 Mtr/yr of an annual production of 0.9 Mte is utilised, predominantly in the cement and concrete industries in Hong Kong.

7.2.2 Beneficial Utilisation of PFA

There is good reason to believe that significantly more PFA could be put to beneficial use in Hong Kong, as achieved elsewhere in the world.

Local and international studies have identified numerous uses for PFA. Those that have potential to consume significant quantities of CLP PFA have been investigated in detail and can be broadly classified in to two groups based on the immediacy of the demand:

- *Options with Quantifiable Market Potential* are those currently consuming PFA in quantity, namely cement, concrete and reclamation/site formation (above waterlevel) or those for which a foreseeable demand could arise given PFA's adoption; below waterlevel reclamation and refuse interleaving material.

- *Other Potential PFA Utilisation Options* are those which could utilise large amounts of PFA, but would require major changes to current practice. These include:

    - Lightweight Aggregates;
    - Autoclaved Aerated Concrete Blocks (AACBs);
    - PFA/Bentonite mix as a Lining and Capping Material for Municipal Landfills;
    - PFA as a Soil Ameliorant or Constituent in the N–Viro Process.

    The above cannot be considered reliable management strategies at this time due to prevailing practices, market conditions, or unresolved environmental and technical issues. Each would require detailed study to investigate market potential, trials to prove technical and environmental acceptability and investment (possibly considerable) by the utility companies. However, the Consultants would recommend that both CLP and Government consider the options and their associated potential benefits to the Territory. Use as lightweight aggregate, in AACBs or as a constituent in the N–Viro process would require processing plant, preferably near to the power stations. It is recommended that a site of about 20–30 hectares is set aside in the Tuen Mun Port Development area for such a PFA utilisation plant.

The more immediate, quantifiable utilisation options are summarised below.

(a) *PFA as a Constituent in Cement Clinker*

PFA is used extensively worldwide as a replacement component in the raw mix in the manufacture of cement clinker. Currently, about 160 Mte/yr of CLP PFA is used by China Cement Company in its Castle Peak kiln, benefiting both companies and Hong Kong's Balance of Trade (by about HK$120 million/yr). Technically, the clinker produced with PFA is indistinguishable from that made with conventional materials.

In addition to the environmental benefits of utilisation, the use of PFA saves energy at CCCs plant that would otherwise be required to grind conventional raw materials and for precalcination.

There is little scope for further increasing the utilisation rate in clinker since CCC operate only a single kiln. The current utilisation is dependent on CCC's plant remaining in operation.

CLP are however concerned that production of clinker could cease due to economic and/or environmental pressures on CCC and they believe that due consideration needs to be taken by the authorities when assessing the problems particular to the cement industry. The Consultants would suggest that, at least account should be taken of the environmental benefits associated with CCC's use of PFA when assessing the overall impact of CCCs operations.

(b) *PFA as a Partial Cement Replacement in Concrete*

PFA is widely used to replace a proportion of the cement used in the production of concrete. Up to 50% of the total cementitious content (TCC) can be PFA, either in the form of blended cements, known as Portland Pulverised Fuel Ash Cement (PPFAC) or by addition of quality controlled PFA in concrete batching.

Use of PFA in this way can improve the technical properties of the product concrete in a number of ways as already demonstrated in Hong Kong. In particular, use of PFA in concrete at up to 25% of TCC will not result in any noticeable adverse effects for most applications.

Economically savings may accrue through reduced raw material costs, but quality control during batching does require increased attention and, potentially cost.

Environmentally, use in concrete affords the benefits of utilisation in general. Associated impacts should not be of concern, particularly if supplied as blended cement or if batching plants conform to procedures such as ISO 9000. This study has addressed potential concerns including:

- local deterioration in air-quality due to fugitive and transport related dust emissions;

- radiation and emissions of radioactive radon on gas from PFA containing concretes;

and concluded no significant adverse environmental impact should result given adequate controls.

Currently, about 80 kte/yr of PFA are utilised in concrete in Hong Kong usually in quantities of less than 25% of TCC, by the private sector and in much of the Government sector, particularly in highways where use is mandatary at 25% of TCC in road paving quality concrete.

Given normal market growth it is projected pessimisticly that an average of 200 kte/yr would be utilised in concrete over the study period.

However, there is considerable potential to increase this figure. Use of PFA in all concrete could be made mandatary, as in countries such as Holland and France. Averaged over the study period, the following are the estimated potential utilisation rates:

- at 15% of TCC - 600 kte/yr
- at 25% of TCC - 1.1 Mte/yr

The above would depend on the availability of compliance grade PFA. CLP, who advocate a mandatary 15% of TCC to be PFA (rising to 25% in later years), are currently installing a classification plant to ensure supply to all potential customers.

Government actions that would benefit utilization include the continuation of the relaxation of restrictions on PFA use by departments, including Housing and BOO, and the consideration of the introduction of statutory requirements including minimum PFA TCC levels and the adoption of a 56 day criterion on concrete strength.

(c) *PFA as an Interleaving Material at Municipal Landfills*

Three large new municipal landfills are currently being planned, all of which will use considerable quantities of inert fill as daily cover or interleaving material to improve appearance and vehicle traction and reduce odourous emissions.

PFA satisfies the basic requirements of an interleaving materials, but its use would require some minor operational changes.

Economically, PFA could only compete with any shortfalls in interleaving material at particular municipal landfills, i.e. that not generated or ordinarily delivered to the site. SENT and particularly the WENT landfill close to the LTPS would fall into this category.

Environmental concerns centre on possible dust-nuisance, potential leaching of toxic metals, and effects on the degradation process of municipal waste. The Consultants have shown that no major problems should result. However, under the Government tendering process use at WENT and SENT is dependent on the contractor demonstrating that PFA is a satisfactory material.

270 Mte/yr and 130 Mte/yr could be utilised at WENT and SENT respectively. The benefits of use at these facilities over that associated with constructing new dedicated PFA disposal sites, merit a strong consideration of PFA's use.

(d) *PFA as Reclamation Material*

Territory wide fill requirements in the foreseeable future exceed 15 Mm^3/yr, mostly for underwater fill for foreshore reclamation. PFA has been used on numerous occasions for site formation or reclamation, but is currently only actively approved by Government for above water–level applications, although the situation is changing, even over the course of the study, with the FMC actively seeking ways to utilise more PFA.

Currently, about 100 kte/yr of PFA is used in reclamation. For this level to increase markedly, PFA would need to be utilised in underwater reclamations. Such use would not be unheralded, with experience in Japan, UK and to a limited extent in Hong Kong.

Reclamation requires large, intermittent supplies of fill materials, rather than the smaller continuous demand of the options discussed above. Hence, a temporary storage facility will be required, unless PFA could be mixed randomly with other fill sources. Geotechnically, PFA satisfies the requirements of a reclamation fill, being *"as good if not better than soils commonly used in Hong Kong"*[(39)]. Harvesting of stored PFA from Tsang Tsui ash lagoons should not present any obstacle to PFA's use, based on UK experience.

The cost of PFA fill would be economic in respect of the alternatives, since CLP do not charge for the ash, costs are those associated with harvesting and transport.

Environmental benefits of using alternatives to marine dredged sand, of which there is a shortage, are apparent. Environmental concerns over the use of PFA on–land have been largely addressed by previous studies; namely those of leachate, radioactivity, plant pollution and noise. When placed underwater, or when buildings are constructed on PFA reclamations, the Consultants have found no significant basis to these concerns, provided adequate and simple measures are instituted. The results of an on–going trials at Lung Kwu Sheung Tan Bay should allay any remaining environmental concerns.

Potentially, all PFA not utilised elsewhere could be employed as reclamation fill. Large reclamations are planned in close proximity to the LTPS site that could benefit CLP by emptying Tsang Tsui lagoons whilst users would gain economic advantage. WENT, SENT and Tuen Mun Port alone could use up to 5 Mte of PFA.

The Consultants are aware that Government's approach to PFA as an underwater fill may change in the near future. The encouragement of PFA's use is recommended if the trial proves a success. CLP advocate PFA's mandatory use ahead of other fills when it is available in sufficient quantity.

(e) *Utilisation Rates*

On the basis of the options with identifiable market potential described above the Consultants have estimated three utilisation rates:

- *Present Utilisation* at 340 kte/yr;
- *Projected Utilisation* at 730 kte/yr, i.e. that readily achievable;
- *Potential Utilisation* at 1.1 Mte/yr on a continuous use basis, or all PFA arisings if potential reclamation use were realised.

These utilisation rates have been used to aid ranking of the relative merits of the various disposal sites under different firing scenarios.

7.2.3 *Disposal of PFA*

Disposal facilities will be required for PFA arisings from CPPS and the LTPS at Black Point which cannot be utilised elsewhere. Any disposal facilities must also afford back up capacity for all arisings if future utilisation schemes fail.

The study assessed each of the options given in *Section 7.1.3* and arrived at the following general conclusions for feasible options in roughly the order of merit each option ought to be persued.

(i) Tsang Tsui Ash Lagoons

Regardless of utilisation rate or firing scenario the continued use and extension to the life of the lagoons is a favoured option since this puts off (maybe indefinitely) the time when a new disposal facility must be developed. The lagoons can also act as a storage facility of PFA not required by continuous users that could later be harvested for use in reclamation. Given continuation of present utilisation, detailed planning for extended lagoons (or a new facility) need not commence until 1995 or 1996 for *Scenario I* and *II* respectively, allowing 3 years for design, EIA and construction.

Under *Scenario II*, it will be possible to continue operation under the existing licence for almost a decade, and given projected growth in utilisation for almost the entire 20 year period.

On the basis of the above the Consultants recommend the utility and Government investigate prior to 1995 the possibility of resolving constraints to the continued use of the lagoons beyond 2011 (PADS) and the relocation of the BBC radio station to higher ground.

(ii) Quarries and Landfills

Designated PFA landfills are favoured over use of quarries at lower utilisation rates on capacity and economic considerations. The ranking order LF2, LF1 (or LF1 + LF2), LF4 generally holds, more strongly if the proposed PAA borrow in the LF1/LF2 area goes ahead. Given higher utilisation, capacity becomes less important and the environmental advantages of quarry restoration become more favourable, particularly if development of any landfill can be avoided. This would only result if both quarries could be used in sequence for dedicated PFA disposal facilities. Use of quarry sites for disposal of other potential by–products is considered below.

(iii) Disposal at Sea

Of the disposal at sea options investigated, only unconfined marine dumping outside Hong Kong waters has scope as a management strategy. Dumping at the Pearl River mouth (Lema Channel) would require agreement of the Chinese authorities.

The Consultants would maintain that dumping over 3 Mte/yr via marine disposal of a potentially useful resource is of dubious value. However, without adequate monitoring of similar scale operations (there are none) it is difficult to conclude that it would be environmentally damaging. Such an operation would, however, go against the tenor and spirit of International Conventions on prevention of dumping at sea but could be sanctioned by the competent authority (EPD).

The Consultants would recommend that Sea Dumping of PFA, outside Hong Kong waters is pursued only when, and if, all other options are exhausted.

7.2.4 *Conclusions*

The study has shown that given a concerted and continuous effort on behalf of CLP and encouragement by Government, the whole issue of PFA disposal could disappear and all arisings could be put to use to the benefit of the Territory, without giving rise to significant adverse impact.

7.3 *FURNACE BOTTOM ASH (FBA) MANAGEMENT STRATEGY*

7.3.1 *Introduction*

FBA is that portion of the ash in the raw coal that is not carried out of the furnace with the flue gases, instead it collects at the furnace bottom. CLP produce about 1 te of FBA for each 9 te of PFA. They could be producing upto 350 kte/yr in 2016. HEC are expected to be producing 170 kte/yr by this time, giving a territory wide cumulative total of 9 Mte in 2016.

FBA has commercial value and is currently sold in Hong Kong to manufacture concrete blocks. However, CLP are concerned that the existing market could soon become saturated and hence the study has investigated other potential markets and back-up disposal options.

7.3.2 *Beneficial Utilisation of FBA*

(a) *FBA in the Manufacture of Concrete Blocks*

Currently, all CLP FBA is sold to Kin Ching Besser Company for the manufacture of lightweight concrete blocks, affording both technical and economic benefit to the company in comparison to the use of conventional aggregate.

Environmental benefits are the elimination of the need for disposal of FBA and of quarrying alternatives. The impact of Kin Ching Besser's Operations are not known to be significant.

Block manufacture is the only FBA utilisation strategy with *quantifiable market potential*. Current utilisation stands at 130 kte/yr. There is little current scope for increasing this despite a market that could absorb all FBA likely to be produced, due to the availability of low priced imported blocks.

Increasing utilisation would probably require price reductions from CLP and investment in a further block manufacturing plant. A 20 ha site for such a plant could be set aside by Government within the TMP development area close to the FBA producing plants.

(b) Other Potential FBA Utilisation Options

The study has investigated the potential of the following utilisation options that could utilise large amounts of FBA.

- *Aggregates Replacement*: Appreciable quantities of FBA could be utilised as a sub-base material in road construction, free draining material in infrastructural projects or as hardcore for temporary standing areas, but utilisation would be dependent on a series of demonstrations by CLP and appropriate marketing.

- *Use mixed with PFA as an Interleaving Material or in Reclamation*: If either of these strategies were realised in respect of PFA, the properties of a PFA/FBA mix would only enhance the suitability of ash utilisation. However, since FBA is a product of value such a strategy should only be pursued as an alternative to FBA disposal.

The study has considered two utilisation rates when considering disposal facility requirements:

- *Present Utilisation* at 130 kte/yr
- *Potential Utilisation* consuming all FBA arisings

7.3.3 *Disposal of FBA*

Consideration has been given to ensure adequate secure disposal capacity for excess FBA that cannot be utilised or that could accommodate all FBA were utilisation to fail.

Potential disposal options are linked closely to those selected for excess PFA arisings since, in most instances, it will be preferable to dispose FBA in separate areas of any PFA disposal facility rather than develop further new facilities. The effect of the lifespan of any PFA disposal facility is unlikely to be significant.

PFA landfill sites with lifespans of over 10 years from when Tsang Tsui is full, would see their working life cut between 5 and 10% at most. This does not effect the ranking given in *Section 7.2.3*.

Either of the two quarry sites could accommodate all FBA arisings over the study period, but since it may later be utilised the benefits of quarry restoration cannot be guaranteed.

Hence, preferred disposal routes for excess FBA are ranked as follows for both *Scenario I and II.*

- Separate area at Tsang Tsui - current licence capacity
- Separate area at Tsang Tsui - extended capacity
- Separate area at PFA Landfill
- Dedicated FBA Quarry disposal site

Before any of these disposal routes could be instituted the constraints to development would require resolution.

Earliest dates at which detailed planning for any FBA facilities would be required are as for PFA – 1995 under *Scenario I* and 1996 for *Scenario II* – allowing three years for planning EIA and construction.

7.3.4 *Conclusions*

All FBA arisings from CLP's facilities should be able to be beneficially utilised given appropriate planning and favourable market conditions. Adequate opportunity exists to develop disposal facilities for FBA that cannot be utilised, either within a separate area of a PFA facility or at a dedicated site.

7.4 *FGD GYPSUM MANAGEMENT STRATEGY*

7.4.1 *Introduction*

Gypsum, calcium sulphate dihydrate, is the principal product of the Limestone/Gypsum FGD process. Arisings would amount to:

- *Scenario I* – upto 8.5 Mte at a rate of 710 kte/yr
- *Scenario II* – upto 4 Mte at a rate of 350 kte/yr
- *HEC* – about 3.5 Mte at a rate of 150 kte/yr if all planned new units use Limestone/Gypsum FGD

FGD gypsum has a range of industrial applications, principly in the manufacture of wallboard for use in the construction industry. CLP's approach to FGD gypsum management is threefold, the latter two being as for fuel ash, i.e. beneficial utilisation followed by disposal. However, the first approach focuses on prevention of arisings via the use of alternative process configurations or FGD systems, namely:

- Re-dissolution of product gypsum in seawater and discharge to sea via the cooling water outfall.
- Use of one of two Seawater FGD systems that also result in gypsum being discharged as dissolved species to sea.

Use of either of the above is dependent on proving the technical and commercial feasibility of the technology and on the impact to the marine environment (see the parallel *Water Quality KIR*[5]). In the event this is not shown, then a FGD gypsum producing process would be adopted, necessitating the by-product management strategy.

7.4.2 *Beneficial Utilisation of FGD Gypsum*

(a) Export

Hongkong Electric are known to have entered into a buy-back arrangement with the supplier of limestone reagent. It is understood the product would be used for wallboard manufacture in Japan. CLP would also consider this option, but have reservations to such 'buy-back' arrangements in respect of:

- *Technical constraints*; to the process configuration and product specification. It is likely that upto 10% would not meet gypsum product quality and would require disposal.

- *Security*; if the export market were to become saturated with domestic FGD gypsum (as is happening in Germany) then any arrangement cannot be guaranteed.

- *Expense*; Costs of such arrangements are inflated over the alternatives.

(b) *Other Potential FGD Gypsum Options*

The local gypsum market is small in comparison to the scale of likely by-product arisings. Hence, local utilisation strategies consuming significant quantities of FGD gypsum must be regarded as speculative at this time and would require long term development. However, the study has identified four utilisation options that appear to have considerable potential in Hong Kong:

- *Wallboard Manufacture*: Could potentially utilise most of the gypsum arisings from the LTPS (upto 90%, 10% of arisings would not meet the specifications required for wallboard), but market outlets do not exist locally and capital for a plant would be a major obstacle.

- *Cement Manufacture*: Up to 100,000 te/yr could be utilised at CCCs kiln (1 LTPS unit output), but technical constraints to this use would have to be overcome.

- *Fill Material*: Use as fill would require the feasibility to be demonstrated. Whilst of long term potential, it is considered an inappropriate strategy at a time when PFA is yet to be fully accepted as a fill material.

- *Artificial Reef Construction*: Also of long term, rather than immediate potential, since trials are just beginning with artificial reefs made of PFA concrete. However, it is likely that trials of several years duration would be required before it can be concluded whether or not FGD gypsum is a suitable reef material in Hong Kong.

In the light of the above the only utilisation rate that can be quantified is the *potential utilisation* of 90% resulting from export, which, if maintained for the 20 year period would reduce arisings requiring disposal from 6.6 Mte to 0.6 Mte – *Scenario I*, average growth – or from 3.7 to 0.4 Mte – *Scenario II*.

7.4.3 *Disposal of FGD Gypsum*

Disposal routes for all FGD gypsum arisings would be required regardless of whether or not a export arrangement were completed, to afford back-up in the event of failure.

Again all disposal options identified would require the resolution of certain constraints. The situation were *Scenario I* firing adopted is particularly critical since arisings would begin in 1996, implying detailed planning must commence in 1993, well before that for any further ash disposal facility.

Marine dumping of solid product may be feasible, but is considered to be an inefficient means of accomplishing disposal at sea and is potentially of greater environmental concern than dissolution and discharge.

Landfill sites would not be suitable to *Scenario I* since they would not be available prior to 1997 (a separate area at Tsang Tsui could possibly act as a temporary storage or small permanent disposal site in the worst case). For *Scenario II* quantities requiring disposal would only suit development of part of a landfill site.

Either quarry site could probably accommodate all LTPS gypsum arisings during the first 20 years of operation under either *Scenarios I or II.*

Disposal routes for LTPS FGD gypsum were ranked as follows (for *Scenarios I and II* except where stated):

- Disposal at Sea;
  - Seawater FGD;
  - Dissolution of Gypsum arisings from Limestone/Gypsum FGD;
  - Marine Dumping in Hong Kong or International Waters.

- Separate area at PFA Landfill (*Scenario II* only).
- Quarry site Q1 or Q2.
- Temporary use of a separate area a Tsang Tsui (*Scenario I*).

Dates at which detailed planning for new facilities should commence are 1993 for *Scenario I* and 2001 under *Scenario II*, allowing three years for planning and construction.

7.4.4 *Conclusions*

Utilisation potential for any FGD gypsum that might arise at the LTPS is not quantifiable. Whilst export may be feasible, local markets would require development. The focus of the management strategy is prevention of arisings via discharge of dissolved gypsum to sea in preference to utilisation or disposal of solid gypsum.

7.5 *WASTEWATER TREATMENT SLUDGE (WTS) MANAGEMENT STRATEGY*

7.5.1 *Introduction*

Wastewater treatment sludge arises from the treatment of the purge stream bled from the absorber of the Limestone/Gypsum FGD system to control the build up of soluble salts. Arisings would amount to:

- *Scenario I* – upto 770 kte at a rate of 65 kte/yr
- *Scenario II* – upto 370 kte at a rate of 32.5 kte/yr
- *HEC* – upto 350 kte at a rate of 15 kte/yr

WTS contains raised levels of certain toxic metals and can have a high COD, making it an unsuitable utilisation material in itself. The management strategy focuses first on prevention of arisings via FGD process configuration if viability can be proved; namely:

- Use of Seawater FGD
- Recycle of the untreated wastewater to the flue gas duct or as a PFA conditioner
- Recycle of the sludge in the furnace or FGD process

If WTS were produced, it might be possible to reduce the quantity requiring special handling via separation of the inert solids and toxic contaminants in the effluent treatment plant.

7.5.2 *Beneficial Utilisation of WTS*

Utilisation options are limited and involve the use of other by-products and additives to form cementitious materials. Potential options identified would require further research and trials to prove environmental acceptability:

- *Artificial Reef Construction*: Trials conducted in the UK and US with concretes incorporating WTS indicate that this may be a potential useful long term outlet for sludge arisings possibly with PFA and/or gypsum (see also *Section 7.4.2*).

- *Reclamation Material*: When mixed in appropriate proportions with PFA, lime and/or cement the treated sludge forms a stabilised cementitious material. This might be suitable for reclamation. It would only be an appropriate strategy when combined with PFA destined for reclamation.

- *Incorporation in the Manufacture of PFA Aggregate, AACBs, FBA Concrete Blocks* or in N-Viro soil for use as interleaving material. Sensitive species would be locked in a cementitious matrix.

7.5.3 *Disposal of WTS*

Potential disposal sites are closely linked to those for FGD gypsum. It might be feasible to simply disperse the sludge amongst the gypsum or place dewatered WTS within a separate area. Viability would depend on whether or not a leachate treatment plant were to be included for gypsum.

WTS could, in theory, be sent to the Centralised Chemical Waste Treatment Facility (CWTF) for stabilisation and subsequent disposal. However, the quantities involved are well in excess of the design capacity of the CWTF capacity and the CWTF was designed to provide a service to small rather than heavy industry. Hence, independent stabilisation by the utilities, which would also utilise quantities of PFA, is preferred. Disposal could then be to municipal landfill (by licence) or to a separate area within any other by-product disposal facility.

7.5.4 *Conclusions*

The Study recommends that the preferred management strategy be if feasible, prevention of arisings of WTS via technology selection. If sludge does arise, it would best be stabilised on-site prior to utilisation or disposal.

7.6 *OVERALL CONCLUSIONS*

The Solid By-Products Key Issue Study has assessed the various options for the prevention, utilisation and disposal of by-products from present and potential coal-fired power plant in respect of impact to the environmental, engineering feasibility and economic viability. The study has considered the 'worst case', in addition to various foreseeable situations in respect of by-product arisings and their utilisation. The following conclusions apply in general terms:

- *Prevention* of arisings via the institution of appropriate technology where feasible, to minimise by-product production is preferred, in particular in respect of FGD.

- *Utilisation* is preferred over disposal and steady continuous commercial outlets for by-products are preferred over intermittent uses, since there would be less need for storage facilities.

- *Disposal* facilities should cater not only for by-products not likely to be utilised, but also afford back-up capacity for all arisings if present or future arisings fail. Development of any new facilities should proceed only when they are required, affording time for utilisation markets to develop.

In respect of the four by-products considered the study has shown that given the institution of a number of recommendations, appropriate technology selection by CLP (if feasible), active promotion by Government Departments, and favourable market conditions all by-product arisings could either be prevented or beneficially utilised.

It is however, unlikely that all by-products could be utilised *as they arise* and quite possible that substantial quantities would not be utilised at all. An assessment of available disposal routes has been undertaken. None are immediately available that could cater for the 'worst case' by-product arisings over the 20 year study period. It is however, likely that the constraints to the use of one or more of the routes identified can be resolved in time to allow detailed planning, given appropriate actions on behalf of Government and CLP. The disposal routes identified as feasible should not give rise to unacceptable environmental impact, but are not entirely without adverse impact. Hence, feasible utilisation that is not unduly onerous in respect of environmental impact or economic implications should be actively pursued.

Electricity is a resource for all industries and residents in Hong Kong, and it is therefore not unreasonable to expect that all Hong Kong (through its representatives in Government) to actively encourage the beneficial utilisation of these by-products and thereby help preserve its environment. In light of the above we would suggest that Government, CLP and other concerned parties institute, where possible, the recommendations of this study.

8. *EPD'S POSITION AND THE WAY FORWARD*

The FGD Process and Gypsum Disposal

Having regard to the findings in the Key Issue Reports on Water Quality and Solid By-product Study, the Director of Environmental Protection has the following views on the FGD process to be adopted and the management strategy for the solid by-product:

(a) for Scenario I (8 coal fired units) and II (4 gas followed by 4 coal-fired units), the limestone/gypsum process is preferred to the seawater scrubbing process. Seawater scrubbing is not considered acceptable from a water quality viewpoint at this stage because it would result in a substantial increase in nitrogen, TSS and heavy metal levels and there are no mitigation measures available at this stage to reduce the pollutant loads;

(b) the limestone/gypsum process will result in the production of gypsum that requires disposal. Gypsum should be treated as an usable resource. EPD prefer the utilisation options as the long term management strategy for solid by-products of the LTPS. A further study should be carried out before the final approval is given to the coal-fired units to examine the following issues in order to establish a management strategy for FGD gypsum:

- the market outlets for the export of gypsum to China or other countries for reuse and recycle must be vigorously explored and fully investigated;
- market outlets for the use of gypsum in local industries should be explored;
- CLP should seriously consider the option of having the "buy-back" arrangement with a limestone supplier. Both the export of gypsum and the buy-back arrangement should be the preferred options;
- as the fall-back option and for temporary storage, the provision of back-up facilities and site for buffer storage for the solid by-product should be considered; and
- the dissolution of solid gypsum in the cooling water should be considered as the very last resort and only after the above options are exhausted. The environmental acceptability of the impacts of any increase in pollutant loads must be confirmed through detailed water quality impact assessment."

Consolidated comments from EPD are presented in *Annex F.*

ANNEXES

Annex A

Annual and Cumulative Raw Material Consumption and By-product Arisings Scenario I

Table A1.1
COAL COMSUMPTION -- Most likely Average, Maximum & Minimum Coal Burn -- Castle Peak A & B and LTPS at Black Point -- SENARIO I

Year	Castle Peak			Black Point			Castle Peak and Black Point			Cumulative		
Given as ktc/yr	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	8050	8010	8090	–	–	–	8050	8010	8090	8050	8010	8090
1993	7820	7720	7930	–	–	–	7820	7720	7930	15870	15730	16020
1994	6870	6650	7080	–	–	–	6870	6650	7080	22740	22380	23100
1995	7080	6780	7360	–	–	–	7080	6780	7360	29820	29160	30460
1996	7320	6970	7640	270	210	330	7590	7180	7970	37410	36340	38430
1997	7320	6920	7690	820	670	1010	8140	7590	8700	45550	43930	47130
1998	7490	7090	7900	1190	910	1450	8680	8000	9350	54230	51930	56480
1999	7860	7360	8330	1360	1070	1580	9220	8430	9910	63450	60360	66390
2000	7910	7450	8420	1920	1400	2380	9830	8850	10800	73280	69210	77190
2001	8210	7640	8760	2220	1690	2650	10430	9330	11410	83710	78540	88600
2002	8310	7790	8870	2800	2040	3500	11110	9830	12370	94820	88370	100970
2003	8580	7990	8910	3150	2310	4430	11730	10300	13340	106550	98670	114310
2004	8670	8200	9040	3800	2580	5300	12470	10780	14340	119020	109450	128650
2005	8750	8420	9160	4500	2850	6190	13250	11270	15350	132270	120720	144000
2006	8980	8430	9609	5000	3420	6911	13980	11850	16520	146250	132570	160520
2007	9060	8620	9609	5740	3770	8041	14800	12390	17650	161050	144960	178170
2008	9140	8670	9609	6560	4330	9221	15700	13000	18830	176750	157960	197000
2009	9609	8870	9609	6991	4730	10481	16600	13600	20090	193350	171560	217090
2010	9609	8920	9609	7941	5350	11811	17550	14270	21420	210900	185830	238510
2011	9609	9040	9609	8681	5670	12687	18290	14710	22296	229190	200540	260806
2012	9609	9190	9609	9531	6010	12687	19140	15200	22296	248330	215740	283101
2013	9609	9190	9609	10421	6600	12687	20030	15790	22296	268360	231530	305397
2014	9609	9270	9609	11211	7020	12687	20820	16290	22296	289180	247820	327693
2015	9609	9609	9609	12201	7251	12687	21810	16860	22296	310990	264680	349988
2016	9609	9609	9609	12687	7801	12687	22296	17410	22296	333286	282090	372284

Table A1.2
COAL– FIRED ELECTRICAL OUTPUT– **Most Likely Average, Maximum & Minimum Production– Castle Peak A & B and LTPS at Black Point– SENARIO I**

Year	**Castle Peak**			**Black Point**			**Castle Peak and Black Point**			**Cumulative**		
Given as MW/yr load factor 73%	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**
1992	3452	3435	3469	–	–	–	3452	3435	3469	3452	3435	3469
1993	3353	3310	3400	–	–	–	3353	3310	3400	6805	6745	6869
1994	2946	2851	3036	–	–	–	2946	2851	3036	9751	9596	9905
1995	3036	2907	3156	–	–	–	3036	2907	3156	12786	12503	13061
1996	3139	2989	3276	116	90	141	3254	3079	3417	16041	15582	16478
1997	3139	2967	3297	352	287	433	3490	3254	3730	19531	18836	20209
1998	3212	3040	3387	510	390	622	3722	3430	4009	23253	22267	24218
1999	3370	3156	3572	583	459	677	3953	3615	4249	27206	25881	28467
2000	3392	3194	3610	823	600	1021	4215	3795	4631	31421	29676	33098
2001	3520	3276	3756	952	725	1136	4472	4001	4892	35893	33677	37990
2002	3563	3340	3803	1201	875	1501	4764	4215	5304	40657	37892	43294
2003	3679	3426	3820	1351	990	1900	5030	4416	5720	45687	42308	49014
2004	3718	3516	3876	1629	1106	2273	5347	4622	6149	51034	46930	55163
2005	3752	3610	3928	1930	1222	2654	5681	4832	6582	56715	51763	61745
2006	3850	3615	4120	2144	1466	2963	5994	5081	7083	62709	56844	68828
2007	3885	3696	4120	2461	1617	3448	6346	5313	7568	69055	62156	76396
2008	3919	3718	4120	2813	1857	3954	6732	5574	8074	75787	67731	84470
2009	4120	3803	4120	2998	2028	4494	7118	5831	8614	82905	73562	93084
2010	4120	3825	4120	3405	2294	5065	7525	6119	9185	90430	79681	102269
2011	4120	3876	4120	3722	2431	5440	7842	6307	9560	98273	85988	111829
2012	4120	3941	4120	4087	2577	5440	8207	6517	9560	106480	92506	121389
2013	4120	3941	4120	4469	2830	5440	8589	6770	9560	115068	99276	130949
2014	4120	3975	4120	4807	3010	5440	8927	6985	9560	123995	106261	140509
2015	4120	4120	4120	5232	3109	5440	9352	7229	9560	133347	113490	150069
2016	4120	4120	4120	5440	3345	5440	9560	7465	9560	142907	120955	159629

Table A1.3
LIMESTONE CONSUMPTION– Most Likely Average, Maximum & Minimum Production
LTPS at Black Point– SENARIO I

Year *Given as kte/yr* *31.1kg/te(coal)*	Black Point Average Growth	 Low Growth	 High Growth	Cumulative Average Growth	 Low Growth	 High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	8.4	6.5	10.3	8.4	6.5	10.3
1997	25.5	20.8	31.4	33.9	27.4	41.7
1998	37.0	28.3	45.1	70.9	55.7	86.8
1999	42.3	33.3	49.1	113.2	88.9	135.9
2000	59.7	43.5	74.0	172.9	132.5	209.9
2001	69.0	52.6	82.4	242.0	185.0	292.3
2002	87.1	63.4	108.9	329.0	248.5	401.2
2003	98.0	71.8	137.8	427.0	320.3	539.0
2004	118.2	80.2	164.8	545.2	400.6	703.8
2005	140.0	88.6	192.5	685.1	489.2	896.3
2006	155.5	106.4	214.9	840.6	595.6	1111.2
2007	178.5	117.2	250.1	1019.1	712.8	1361.3
2008	204.0	134.7	286.8	1223.2	847.5	1648.1
2009	217.4	147.1	326.0	1440.6	994.6	1974.1
2010	247.0	166.4	367.3	1687.6	1161.0	2341.4
2011	270.0	176.3	394.6	1957.6	1337.3	2736.0
2012	296.4	186.9	394.6	2254.0	1524.2	3130.6
2013	324.1	205.3	394.6	2578.1	1729.5	3525.1
2014	348.7	218.3	394.6	2926.8	1947.8	3919.7
2015	379.5	225.5	394.6	3306.2	2173.3	4314.3
2016	394.6	242.6	394.6	3700.8	2415.9	4708.8

Table A1.4
LIME CONSUMPTION – Most Likely Average, Maximum & Minimum Production
LTPS at Black Point – SENARIO I

Year	Black Point			Cumulative		
Given as kte/yr 17.2kg/te(coal)	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	4.6	3.6	5.7	4.6	3.6	5.7
1997	14.1	11.5	17.4	18.7	15.1	23.0
1998	20.5	15.7	24.9	39.2	30.8	48.0
1999	23.4	18.4	27.2	62.6	49.2	75.2
2000	33.0	24.1	40.9	95.6	73.3	116.1
2001	38.2	29.1	45.6	133.8	102.3	161.7
2002	48.2	35.1	60.2	182.0	137.4	221.9
2003	54.2	39.7	76.2	236.2	177.2	298.1
2004	65.4	44.4	91.2	301.5	221.5	389.2
2005	77.4	49.0	106.5	378.9	270.6	495.7
2006	86.0	58.8	118.9	464.9	329.4	614.6
2007	98.7	64.8	138.3	563.6	394.2	752.9
2008	112.8	74.5	158.6	676.5	468.7	911.5
2009	120.3	81.4	180.3	796.7	550.1	1091.8
2010	136.6	92.0	203.2	933.3	642.1	1294.9
2011	149.3	97.5	218.2	1082.6	739.6	1513.2
2012	163.9	103.4	218.2	1246.6	843.0	1731.4
2013	179.2	113.5	218.2	1425.8	956.5	1949.6
2014	192.8	120.7	218.2	1618.7	1077.2	2167.8
2015	209.9	124.7	218.2	1828.5	1202.0	2386.0
2016	218.2	134.2	218.2	2046.7	1336.1	2604.2

Table A1.5
WATER CONSUMPTION – Most Likely Average, Maximum & Minimum Production
LTPS at Black Point – SENARIO I (high grade product)

Year *Given as kte/yr 414.8kg/te(coal)*	**Black Point** Average Growth	Low Growth	High Growth	**Cumulative** Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	112	87	137	112	87	137
1997	340	278	419	452	365	556
1998	494	377	601	946	742	1157
1999	564	444	655	1510	1186	1813
2000	796	581	987	2306	1767	2800
2001	921	701	1099	3227	2468	3899
2002	1161	846	1452	4389	3314	5351
2003	1307	958	1838	5695	4272	7188
2004	1576	1070	2198	7271	5343	9387
2005	1867	1182	2568	9138	6525	11955
2006	2074	1419	2867	11212	7943	14821
2007	2381	1564	3336	13593	9507	18157
2008	2721	1796	3825	16314	11303	21982
2009	2900	1962	4348	19214	13265	26330
2010	3294	2219	4899	22508	15484	31229
2011	3601	2352	5263	26109	17836	36492
2012	3954	2493	5263	30063	20329	41754
2013	4323	2738	5263	34386	23067	47017
2014	4650	2912	5263	39036	25979	52279
2015	5061	3008	5263	44097	28987	57542
2016	5263	3236	5263	49360	32223	62805

Table A1.6
PULVERISED FUEL ASH – Most Likely Average, Maximum & Minimum Production – Castle Peak A & B and LTPS at Black Point – SENARIO I

Year	Castle Peak			Black Point			Castle Peak and Black Point			Cumulative		
Given as kte/yr	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	1159	1153	1165	–	–	–	1159	1153	1165	1159	1153	1165
1993	1126	1112	1142	–	–	–	1126	1112	1142	2285	2265	2307
1994	989	958	1020	–	–	–	989	958	1020	3275	3223	3326
1995	1020	976	1060	–	–	–	1020	976	1060	4294	4199	4386
1996	1054	1004	1100	39	30	48	1093	1034	1148	5387	5233	5534
1997	1054	996	1107	118	96	145	1172	1093	1253	6559	6326	6787
1998	1079	1021	1138	171	131	209	1250	1152	1346	7809	7478	8133
1999	1132	1060	1200	196	154	228	1328	1214	1427	9137	8692	9560
2000	1139	1073	1212	276	202	343	1416	1274	1555	10552	9966	11115
2001	1182	1100	1261	320	243	382	1502	1344	1643	12054	11310	12758
2002	1197	1122	1277	403	294	504	1600	1416	1781	13654	12725	14540
2003	1236	1151	1283	454	333	638	1689	1483	1921	15343	14208	16461
2004	1248	1181	1302	547	372	763	1796	1552	2065	17139	15761	18526
2005	1260	1212	1319	648	410	891	1908	1623	2210	19047	17384	20736
2006	1293	1214	1384	720	492	995	2013	1706	2379	21060	19090	23115
2007	1305	1241	1384	827	543	1158	2131	1784	2542	23191	20874	25656
2008	1316	1248	1384	945	624	1328	2261	1872	2712	25452	22746	28368
2009	1384	1277	1384	1007	681	1509	2390	1958	2893	27842	24705	31261
2010	1384	1284	1384	1144	770	1701	2527	2055	3084	30370	26760	34345
2011	1384	1302	1384	1250	816	1827	2634	2118	3211	33003	28878	37556
2012	1384	1323	1384	1373	865	1827	2756	2189	3211	35760	31067	40767
2013	1384	1323	1384	1501	950	1827	2884	2274	3211	38644	33340	43977
2014	1384	1335	1384	1614	1011	1827	2998	2346	3211	41642	35686	47188
2015	1384	1384	1384	1757	1044	1827	3141	2428	3211	44783	38114	50398
2016	1384	1384	1384	1827	1123	1827	3211	2507	3211	47993	40621	53609

Table A1.7
FURNACE BOTTOM ASH– Most Likely Average, Maximum & Minimum Production– Castle Peak A & B and LTPS at Black Point– SENARIO I

Year	Castle Peak			Black Point			Castle Peak and Black Point			Cumulative		
Given as kte/yr	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	129	128	129	–	–	–	129	128	129	129	128	129
1993	125	124	127	–	–	–	125	124	127	254	252	256
1994	110	106	113	–	–	–	110	106	113	364	358	370
1995	113	108	118	–	–	–	113	108	118	477	467	487
1996	117	112	122	4	3	5	121	115	128	599	581	615
1997	117	111	123	13	11	16	130	121	139	729	703	754
1998	120	113	126	19	15	23	139	128	150	868	831	904
1999	126	118	133	22	17	25	148	135	159	1015	966	1062
2000	127	119	135	31	22	38	157	142	173	1172	1107	1235
2001	131	122	140	36	27	42	167	149	183	1339	1257	1418
2002	133	125	142	45	33	56	178	157	198	1517	1414	1616
2003	137	128	143	50	37	71	188	165	213	1705	1579	1829
2004	139	131	145	61	41	85	200	172	229	1904	1751	2058
2005	140	135	147	72	46	99	212	180	246	2116	1932	2304
2006	144	135	154	80	55	111	224	190	264	2340	2121	2568
2007	145	138	154	92	60	129	237	198	282	2577	2319	2851
2008	146	139	154	105	69	148	251	208	301	2828	2527	3152
2009	154	142	154	112	76	168	266	218	321	3094	2745	3473
2010	154	143	154	127	86	189	281	228	343	3374	2973	3816
2011	154	145	154	139	91	203	293	235	357	3667	3209	4173
2012	154	147	154	153	96	203	306	243	357	3973	3452	4530
2013	154	147	154	167	106	203	320	253	357	4294	3704	4886
2014	154	148	154	179	112	203	333	261	357	4627	3965	5243
2015	154	154	154	195	116	203	349	270	357	4976	4235	5600
2016	154	154	154	203	125	203	357	279	357	5333	4513	5957

Table A1.8
HIGH GRADE GYPSUM (10% moisture) – Most Likely Average, Maximum & Minimum Production
LTPS at Black Point – SENARIO 1

Year	Black Point			Cumulative		
Given as kte/yr 55.8kg/te(coal)	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	15	12	18	15	12	18
1997	46	37	56	61	49	75
1998	66	51	81	127	100	156
1999	76	60	88	203	160	244
2000	107	78	133	310	238	377
2001	124	94	148	434	332	525
2002	156	114	195	590	446	720
2003	176	129	247	766	575	967
2004	212	144	296	978	719	1263
2005	251	159	345	1229	878	1608
2006	279	191	386	1508	1069	1994
2007	320	210	449	1829	1279	2443
2008	366	242	515	2195	1521	2957
2009	390	264	585	2585	1784	3542
2010	443	299	659	3028	2083	4201
2011	484	316	708	3512	2399	4909
2012	532	335	708	4044	2735	5617
2013	582	368	708	4626	3103	6325
2014	626	392	708	5251	3495	7033
2015	681	405	708	5932	3899	7741
2016	708	435	708	6640	4335	8449

Table A1.9
WASTEWATER SLUDGE (IAR base)– Most Likely Average, Maximum & Minimum Production
LTPS at Black Point– SENARIO I

Year *Given as kte/yr 5.1kg/te(coal)*	**Black Point** Average Growth	Low Growth	High Growth	**Cumulative** Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	1.4	1.1	1.7	1.4	1.1	1.7
1997	4.2	3.4	5.2	5.6	4.5	6.8
1998	6.1	4.6	7.4	11.6	9.1	14.2
1999	6.9	5.5	8.1	18.6	14.6	22.3
2000	9.8	7.1	12.1	28.4	21.7	34.4
2001	11.3	8.6	13.5	39.7	30.3	47.9
2002	14.3	10.4	17.9	54.0	40.7	65.8
2003	16.1	11.8	22.6	70.0	52.5	88.4
2004	19.4	13.2	27.0	89.4	65.7	115.4
2005	23.0	14.5	31.6	112.4	80.2	147.0
2006	25.5	17.4	35.2	137.9	97.7	182.2
2007	29.3	19.2	41.0	167.1	116.9	223.2
2008	33.5	22.1	47.0	200.6	139.0	270.3
2009	35.7	24.1	53.5	236.2	163.1	323.7
2010	40.5	27.3	60.2	276.7	190.4	384.0
2011	44.3	28.9	64.7	321.0	219.3	448.7
2012	48.6	30.7	64.7	369.6	250.0	513.4
2013	53.1	33.7	64.7	422.8	283.6	578.1
2014	57.2	35.8	64.7	480.0	319.4	642.8
2015	62.2	37.0	64.7	542.2	356.4	707.5
2016	64.7	39.8	64.7	606.9	396.2	772.2

Annex B

Annual and Cumulative Raw Material Consumption and By-product Arisings Scenario II

Table B1.1

COAL COMSUMPTION – Most likely Average, Maximum & Minimum Coal Burn – Castle Peak A & B and LTPS at Black Point – SENARIO II

Year	Castle Peak			Black Point			Castle Peak and Black Point			Cumulative		
Given as kte/yr	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	8050	8010	8090	–	–	–	8050	8010	8090	8050	8010	8090
	7820	7720	7930	–	–	–	7820	7720	7930	15870	15730	16020
	6870	6650	7080	–	–	–	6870	6650	7080	22740	22380	23100
1995	7080	6780	7360	–	–	–	7080	6780	7360	29820	29160	30460
	7320	6970	7640	–	–	–	7320	6970	7640	37140	36130	38100
	7320	6920	7690	–	–	–	7320	6920	7690	44460	43050	45790
1998	7490	7090	7900	–	–	–	7490	7090	7900	51950	50140	53690
	7860	7360	8330	–	–	–	7860	7360	8330	59810	57500	62020
	7910	7450	8420	–	–	–	7910	7450	8420	67720	64950	70440
2001	8210	7640	8760	–	–	–	8210	7640	8760	75930	72590	79200
	8310	7790	8870	–	–	–	8310	7790	8870	84240	80380	88070
	8580	7990	8910	–	–	–	8580	7990	8910	92820	88370	96980
2004	8670	8200	9040	1586	1586	1586	10256	9786	10626	103076	98156	107606
	8750	8420	9160	3172	2850	3172	11922	11270	12332	114998	109426	119938
	8980	8430	9609	3172	3172	3992	12152	11602	13600	127149	121028	133538
2007	9060	8620	9609	4758	3770	6344	13818	12390	15952	140967	133418	149490
	9140	8670	9609	6344	4330	6344	15484	13000	15952	156451	146418	165442
	9609	8870	9609	6344	4730	6344	15952	13600	15952	172403	160018	181394
2010	9609	8920	9609	6344	5350	6344	15952	14270	15952	188355	174288	197347
	9609	9040	9609	6344	5670	6344	15952	14710	15952	204307	188998	213299
	9609	9190	9609	6344	6010	6344	15952	15200	15952	220259	204198	229251
2013	9609	9190	9609	6344	6344	6344	15952	15534	15952	236211	219732	245203
	9609	9270	9609	6344	6344	6344	15952	15614	15952	252163	235346	261155
	9609	9609	9609	6344	6344	6344	15952	15952	15952	268116	251298	277107
2016	9609	9609	9609	6344	6344	6344	15952	15952	15952	284068	267250	293059

Table B1.2

COAL– FIRED ELECTRICAL OUTPUT– **Most Likely Average, Maximum & Minimum Production– Castle Peak A & B and LTPS at Black Point– SENARIO II**

Year	**Castle Peak**			**Black Point**			**Castle Peak and Black Point**			**Cumulative**		
Given as MW/yr load factor 73%	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**
1992	3452	3435	3469	–	–	–	3452	3435	3469	3452	3435	3469
1993	3353	3310	3400	–	–	–	3353	3310	3400	6805	6745	6869
1994	2946	2851	3036	–	–	–	2946	2851	3036	9751	9596	9905
1995	3036	2907	3156	–	–	–	3036	2907	3156	12786	12503	13061
1996	3139	2989	3276	–	–	–	3139	2989	3276	15925	15492	16337
1997	3139	2967	3297	–	–	–	3139	2967	3297	19064	18459	19634
1998	3212	3040	3387	–	–	–	3212	3040	3387	22275	21499	23021
1999	3370	3156	3572	–	–	–	3370	3156	3572	25645	24655	26593
2000	3392	3194	3610	–	–	–	3392	3194	3610	29037	27849	30203
2001	3520	3276	3756	–	–	–	3520	3276	3756	32557	31125	33960
2002	3563	3340	3803	–	–	–	3563	3340	3803	36121	34466	37763
2003	3679	3426	3820	–	–	–	3679	3426	3820	39800	37892	41583
2004	3718	3516	3876	680	680	680	4398	4196	4556	44197	42088	46140
2005	3752	3610	3928	1360	1222	1360	5112	4832	5288	49309	46920	51427
2006	3850	3615	4120	1360	1360	1712	5210	4975	5832	54519	51895	57259
2007	3885	3696	4120	2040	1617	2720	5925	5313	6840	60444	57207	64099
2008	3919	3718	4120	2720	1857	2720	6639	5574	6840	67083	62781	70939
2009	4120	3803	4120	2720	2028	2720	6840	5831	6840	73923	68613	77779
2010	4120	3825	4120	2720	2294	2720	6840	6119	6840	80763	74732	84619
2011	4120	3876	4120	2720	2431	2720	6840	6307	6840	87603	81039	91459
2012	4120	3941	4120	2720	2577	2720	6840	6517	6840	94443	87557	98299
2013	4120	3941	4120	2720	2720	2720	6840	6661	6840	101283	94217	105139
2014	4120	3975	4120	2720	2720	2720	6840	6695	6840	108123	100912	111979
2015	4120	4120	4120	2720	2720	2720	6840	6840	6840	114963	107752	118819
2016	4120	4120	4120	2720	2720	2720	6840	6840	6840	121803	114592	125659

Table B1.3
LIMESTONE CONSUMPTION – Most Likely Average, Maximum & Minimum Production
LTPS at Black Point – SENARIO II

Year	Black Point			Cumulative		
Given as kte/yr 31.1kg/te(coal)	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	–	–	–	–	–	–
1997	–	–	–	–	–	–
1998	–	–	–	–	–	–
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	–	–	–	–	–	–
2002	–	–	–	–	–	–
2003	–	–	–	–	–	–
2004	49.3	49.3	49.3	49.3	49.3	49.3
2005	98.6	88.6	98.6	148.0	138.0	148.0
2006	98.6	98.6	124.1	246.6	236.6	272.1
2007	148.0	117.2	197.3	394.6	353.9	469.4
2008	197.3	134.7	197.3	591.9	488.5	666.7
2009	197.3	147.1	197.3	789.1	635.6	864.0
2010	197.3	166.4	197.3	986.4	802.0	1061.2
2011	197.3	176.3	197.3	1183.7	978.3	1258.5
2012	197.3	186.9	197.3	1381.0	1165.3	1455.8
2013	197.3	197.3	197.3	1578.3	1362.5	1653.1
2014	197.3	197.3	197.3	1775.6	1559.8	1850.4
2015	197.3	197.3	197.3	1972.8	1757.1	2047.7
2016	197.3	197.3	197.3	2170.1	1954.4	2244.9

Table B1.4
LIME CONSUMPTION – Most Likely Average, Maximum & Minimum Production
LTPS at Black Point – SENARIO II

Year *Given as kte/yr 17.2kg/te(coal)*	**Black Point** Average Growth	Low Growth	High Growth	**Cumulative** Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	–	–	–	–	–	–
1997	–	–	–	–	–	–
1998	–	–	–	–	–	–
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	–	–	–	–	–	–
2002	–	–	–	–	–	–
2003	–	–	–	–	–	–
2004	27.3	27.3	27.3	27.3	27.3	27.3
2005	54.6	49.0	54.6	81.8	76.3	81.8
2006	54.6	54.6	68.7	136.4	130.9	150.5
2007	81.8	64.8	109.1	218.2	195.7	259.6
2008	109.1	74.5	109.1	327.3	270.2	368.7
2009	109.1	81.4	109.1	436.4	351.5	477.8
2010	109.1	92.0	109.1	545.5	443.6	586.9
2011	109.1	97.5	109.1	654.7	541.1	696.0
2012	109.1	103.4	109.1	763.8	644.4	805.1
2013	109.1	109.1	109.1	872.9	753.6	914.3
2014	109.1	109.1	109.1	982.0	862.7	1023.4
2015	109.1	109.1	109.1	1091.1	971.8	1132.5
2016	109.1	109.1	109.1	1200.2	1080.9	1241.6

Table B1.5
WATER CONSUMPTION – Most Likely Average, Maximum & Minimum Production
LTPS at Black Point – SENARIO II (high grade product)

Year	**Black Point**			**Cumulative**		
Given as kte/yr 414.8kg/te(coal)	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	–	–	–	–	–	–
1997	–	–	–	–	–	–
1998	–	–	–	–	–	–
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	–	–	–	–	–	–
2002	–	–	–	–	–	–
2003	–	–	–	–	–	–
2004	658	658	658	658	658	658
2005	1316	1182	1316	1973	1840	1973
2006	1316	1316	1656	3289	3156	3629
2007	1973	1564	2631	5263	4720	6261
2008	2631	1796	2631	7894	6516	8892
2009	2631	1962	2631	10525	8478	11523
2010	2631	2219	2631	13156	10697	14154
2011	2631	2352	2631	15788	13049	16786
2012	2631	2493	2631	18419	15542	19417
2013	2631	2631	2631	21050	18173	22048
2014	2631	2631	2631	23682	20805	24680
2015	2631	2631	2631	26313	23436	27311
2016	2631	2631	2631	28944	26067	29942

Table B1.6
PULVERISED FUEL ASH– **Most Likely Average, Maximum & Minimum Production– Castle Peak A & B and LTPS at Black Point– SENARIO II**

Year	**Castle Peak**			**Black Point**			**Castle Peak and Black Point**			**Cumulative**		
Given as kte/yr	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**
1992	1159	1153	1165	–	–	–	1159	1153	1165	1159	1153	1165
1993	1126	1112	1142	–	–	–	1126	1112	1142	2285	2265	2307
1994	989	958	1020	–	–	–	989	958	1020	3275	3223	3326
1995	1020	976	1060	–	–	–	1020	976	1060	4294	4199	4386
1996	1054	1004	1100	–	–	–	1054	1004	1100	5348	5203	5486
1997	1054	996	1107	–	–	–	1054	996	1107	6402	6199	6594
1998	1079	1021	1138	–	–	–	1079	1021	1138	7481	7220	7731
1999	1132	1060	1200	–	–	–	1132	1060	1200	8613	8280	8931
2000	1139	1073	1212	–	–	–	1139	1073	1212	9752	9353	10143
2001	1182	1100	1261	–	–	–	1182	1100	1261	10934	10453	11405
2002	1197	1122	1277	–	–	–	1197	1122	1277	12131	11575	12682
2003	1236	1151	1283	–	–	–	1236	1151	1283	13366	12725	13965
2004	1248	1181	1302	228	228	228	1477	1409	1530	14843	14134	15495
2005	1260	1212	1319	457	410	457	1717	1623	1776	16560	15757	17271
2006	1293	1214	1384	457	457	575	1750	1671	1958	18310	17428	19229
2007	1305	1241	1384	685	543	913	1990	1784	2297	20299	19212	21527
2008	1316	1248	1384	913	624	913	2230	1872	2297	22529	21084	23824
2009	1384	1277	1384	913	681	913	2297	1958	2297	24826	23043	26121
2010	1384	1284	1384	913	770	913	2297	2055	2297	27123	25097	28418
2011	1384	1302	1384	913	816	913	2297	2118	2297	29420	27216	30715
2012	1384	1323	1384	913	865	913	2297	2189	2297	31717	29404	33012
2013	1384	1323	1384	913	914	913	2297	2237	2297	34014	31641	35309
2014	1384	1335	1384	913	914	913	2297	2248	2297	36312	33890	37606
2015	1384	1384	1384	913	913	913	2297	2297	2297	38609	36187	39903
2016	1384	1384	1384	913	913	913	2297	2297	2297	40906	38484	42201

Table B1.7

FURNACE BOTTOM ASH – Most Likely Average, Maximum & Minimum Production – Castle Peak A & B and LTPS at Black Point – SENARIO II

Year	Castle Peak			Black Point			Castle Peak and Black Point			Cumulative		
Given as kte/yr	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	129	128	129	–	–	–	129	128	129	129	128	129
1993	125	124	127	–	–	–	125	124	127	254	252	256
1994	110	106	113	–	–	–	110	106	113	364	358	370
1995	113	108	118	–	–	–	113	108	118	477	467	487
1996	117	112	122	–	–	–	117	112	122	594	578	610
1997	117	111	123	–	–	–	117	111	123	711	689	733
1998	120	113	126	–	–	–	120	113	126	831	802	859
1999	126	118	133	–	–	–	126	118	133	957	920	992
2000	127	119	135	–	–	–	127	119	135	1084	1039	1127
2001	131	122	140	–	–	–	131	122	140	1215	1161	1267
2002	133	125	142	–	–	–	133	125	142	1348	1286	1409
2003	137	128	143	–	–	–	137	128	143	1485	1414	1552
2004	139	131	145	25	25	25	164	157	170	1649	1570	1722
2005	140	135	147	51	46	51	191	180	197	1840	1751	1919
2006	144	135	154	51	51	64	194	186	218	2034	1936	2137
2007	145	138	154	76	60	101	221	198	255	2255	2135	2392
2008	146	139	154	101	69	101	248	208	255	2503	2343	2647
2009	154	142	154	101	76	101	255	218	255	2758	2560	2902
2010	154	143	154	101	86	101	255	228	255	3014	2789	3158
2011	154	145	154	101	91	101	255	235	255	3269	3024	3413
2012	154	147	154	101	96	101	255	243	255	3524	3267	3668
2013	154	147	154	101	102	101	255	249	255	3779	3516	3923
2014	154	148	154	101	102	101	255	250	255	4035	3766	4178
2015	154	154	154	101	101	101	255	255	255	4290	4021	4434
2016	154	154	154	101	101	101	255	255	255	4545	4276	4689

Table B1.8
HIGH GRADE GYPSUM (10% moisture)– Most Likely Average, Maximum & Minimum Production
LTPS at Black Point– SENARIO II

Year	Black Point			Cumulative		
Given as kte/yr 55.8kg/te(coal)	Average Growth	Low Growth	High Growth	Average Growth	Low Growth	High Growth
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	–	–	–	–	–	–
1997	–	–	–	–	–	–
1998	–	–	–	–	–	–
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	–	–	–	–	–	–
2002	–	–	–	–	–	–
2003	–	–	–	–	–	–
2004	88	88	88	88	88	88
2005	177	159	177	265	248	265
2006	177	177	223	442	425	488
2007	265	210	354	708	635	842
2008	354	242	354	1062	876	1196
2009	354	264	354	1416	1140	1550
2010	354	299	354	1770	1439	1904
2011	354	316	354	2124	1755	2258
2012	354	335	354	2478	2091	2612
2013	354	354	354	2832	2445	2966
2014	354	354	354	3186	2799	3320
2015	354	354	354	3540	3153	3674
2016	354	354	354	3894	3507	4028

Table B1.9
WASTEWATER SLUDGE (IAR base)– Most Likely Average, Maximum & Minimum Production
LTPS at Black Point– SENARIO II

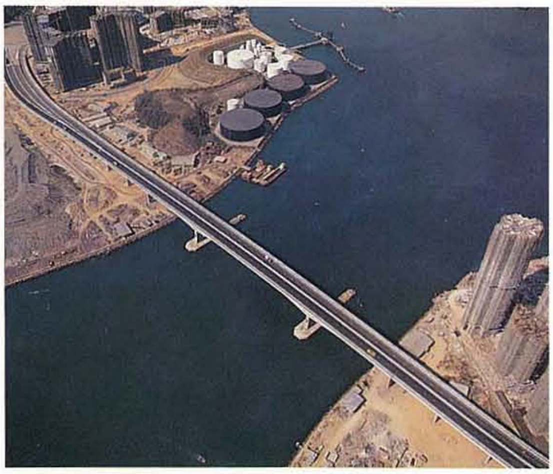
Year	**Black Point**			**Cumulative**		
Given as kte/yr 5.1kg/te(coal)	**Average Growth**	**Low Growth**	**High Growth**	**Average Growth**	**Low Growth**	**High Growth**
1992	–	–	–	–	–	–
1993	–	–	–	–	–	–
1994	–	–	–	–	–	–
1995	–	–	–	–	–	–
1996	–	–	–	–	–	–
1997	–	–	–	–	–	–
1998	–	–	–	–	–	–
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	–	–	–	–	–	–
2002	–	–	–	–	–	–
2003	–	–	–	–	–	–
2004	8.1	8.1	8.1	8.1	8.1	8.1
2005	16.2	14.5	16.2	24.3	22.6	24.3
2006	16.2	16.2	20.4	40.4	38.8	44.6
2007	24.3	19.2	32.4	64.7	58.0	77.0
2008	32.4	22.1	32.4	97.1	80.1	109.3
2009	32.4	24.1	32.4	129.4	104.2	141.7
2010	32.4	27.3	32.4	161.8	131.5	174.0
2011	32.4	28.9	32.4	194.1	160.4	206.4
2012	32.4	30.7	32.4	226.5	191.1	238.7
2013	32.4	32.4	32.4	258.8	223.4	271.1
2014	32.4	32.4	32.4	291.2	255.8	303.4
2015	32.4	32.4	32.4	323.5	288.1	335.8
2016	32.4	32.4	32.4	355.9	320.5	368.1

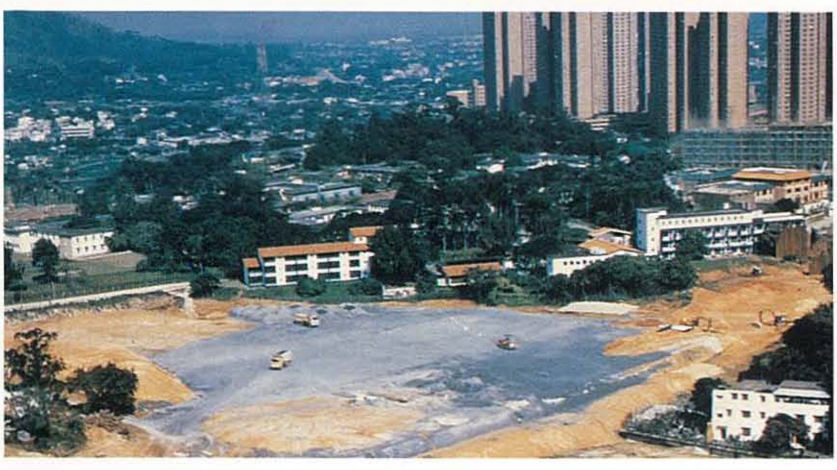
Annex C

PFA Utilisation - CLP 'Ash Marketing' Publications

PFA for Hong Kong
香港煤灰的應用

An introduction to Pulverized Fuel Ash　　煤灰簡介





Introduction

In order to maintain electricity prices at the lowest practical level, Hong Kong's modern power stations have gradually replaced oil by coal as their primary fuel since 1982.

The Castle Peak Power Stations operated by China Light & Power Co., Ltd. burn nearly 10 million tonnes of coal per year, producing around one million tonnes of coal ash.

Part of this ash is sold into the building and construction industries, with any surplus being used by China Light or stored in lagoons.

China Light is further developing the industrial applications of ash in Hong Kong. This benefits electricity consumers and tax payers by reducing the need for disposal, whilst providing the construction industry with a locally sourced raw material that is relatively abundant, versatile and inexpensive.

This brochure gives a brief description of ash and its many uses and benefits for Hong Kong. Potential users are advised to obtain early technical advice when ash is being considered for a project.

前言

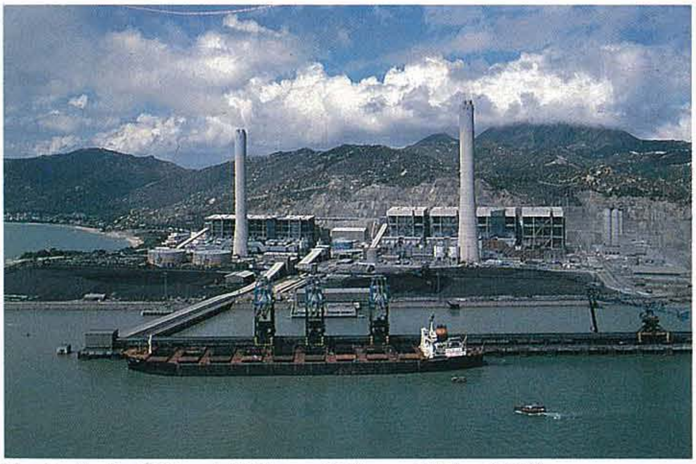
香港的現代化電廠，自1982年以來，逐步以煤作爲主要燃料，使電力價格得以維持在合理水平。

由中電經營的青山發電廠，每年耗煤近一千萬噸，生產煤灰約一百萬噸。

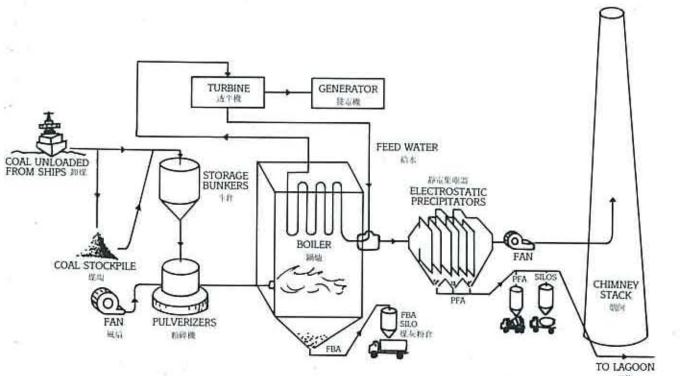
目前，部份煤灰售予建造業，其餘則由中電自用，或存放在煤灰湖中。

中電現正在本港進一步拓展煤灰的工業用途，此舉對電力用戶及納稅人均有裨益，除可削減需棄置的數量外，又爲本港建造業開闢一項廉價，用途廣而供應足的本地原料。

此單張簡述煤灰的性質及其衆多用途與優點，擬在建造工程上採用煤灰者，可先向專業人士徵詢煤灰使用方面的技術資料。



The Castle Peak 'A' and 'B' Power Stations. 青山A、B電廠



Ash production at China Light's Power Stations. 中電電廠生產煤灰過程

The PFA silos at the Castle Peak Power Stations.
青山電廠煤灰粉倉

The Tsang Tsui ash lagoons. 曾嘴煤灰湖

Ash Production

Around 90% of the ash arising from the combustion of coal is carried out of the boilers in the flue gases and extracted by electrostatic precipitators in the form of a fine grey powder known as Pulverized Fuel Ash (PFA), or 'fly ash' in some countries.

煤灰生產過程

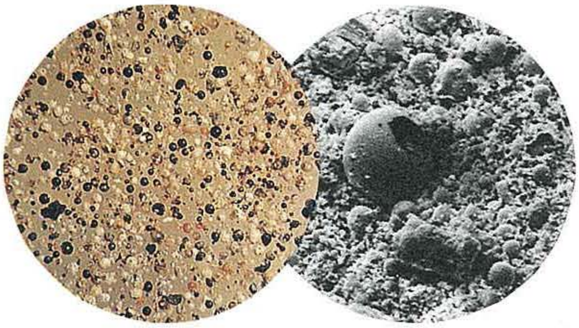
燃煤過程中，約有90%煤灰混在烟氣中帶出鍋爐，再由靜電除塵器收集，灰色細粉狀的煤灰，稱爲粉狀煤灰（PFA），在一些國家也叫飛灰。

收集後的煤灰由抽風機轉運入缸，再以密封式水泥缸經水路或陸路供應市場。如需濕灰，則經拌灰機另加淡水，這類“調濕煤灰”可以用作填海，一般用貨車或駁船供應市場。

The PFA is then transported pneumatically to silos from which it can be supplied dry in road or marine tankers. When not required in its dry state, it is passed through a mixing plant where fresh water is added. It is then known as 'conditioned PFA' which can be supplied in barges or road vehicles for use as a fill material.

PFA which is surplus to immediate requirements is transported hydraulically to lagoons. This PFA is known as 'lagoon ash' and can be subsequently reclaimed for use as a bulk fill.

The remainder of the ash (about 10%) is coarser and is called Furnace Bottom Ash (FBA). FBA falls to the bottom of the furnace into a hopper and is removed by conveyors or sluiceways to silos or storage pits.



PFA viewed under light and electron microscopes.
光線及電子顯微鏡下煤灰粉結構

Material Properties

PFA is a glassy material which derives from particles of rock included in the coal. Its principal constituents are thus silica, alumina, iron and calcium, whilst other combustion products are present in much smaller quantities. Due to their generation at temperatures of 1400°C to 1700°C in the power station boilers, these compounds are highly stable.

Physically, PFA consists predominantly of spherical particles ranging in size from 1 to 200 microns.

The following main properties are important in the industrial use of PFA:

- It is a fine lightweight powder
- It combines with free lime (pozzolanic activity)
- It has predominantly rounded particles
- In bulk form, it takes up water

As a consequence of these properties, PFA has become an important raw material in the building and construction industries worldwide, where it can be used as structural fill, in block and lightweight aggregate manufacture, concrete and cement, grout, stabilisation and brickmaking.

Over 2.5 million tonnes of the PFA produced in Hong Kong have been used in such applications in the territory, Macau and China while over 50 million tonnes are used each year worldwide.

PFA is also used as a filler in industries as diverse as refractories, paints, plastics, chemicals, filtration, insulation and fire protection. More applications are possible when binders, such as organic resins, are used with PFA.

FBA has similar properties and chemical composition to PFA, but generally comprises particles ranging in size from 30mm to less than 50 microns.

剩餘的煤灰混和海水後，經地下管道，泵送往距離發電廠約七公里的一個煤灰湖中，日後可以挖起，作爲塡土料。

其餘有約10%比較粗的煤灰，稱爲爐底灰（FBA），積聚在鍋爐底的灰斗中，由輸送帶或水槽送缸或存放灰坑中。

煤灰的質料性能

煤灰料爲玻璃質，源出煤中所含顆粒。主要成份多爲硅石，礬石，鐵及鈣等，還有少量其他燃燒產物。由於電鍋爐出灰溫度爲攝氏1400至1700度，灰粉中的化合物特性十分穩定。

外形上，煤灰以球形顆粒爲主，大小由1至200微米。

煤灰可作爲混凝土材料，因其具備以下四大特質：

* 幼細而輕的粉粒
* 與生石灰化合（硬結性）
* 顆粒以球狀爲主
* 鬆散吸水

由於上述特質，煤灰已成爲多個國家樓宇建築主要原料，用於結構塡料、製造輕質合成混凝土及水泥、灌漿、穩定用添加料及製磚材料。

港、澳及中國建築業迄今已使用本港產煤灰超過二百五十萬噸，世界上每年用煤灰數量超過五千萬噸。

工業上也用煤灰作爲耐火磚、漆、塑膠、化學劑、過濾、絕緣及防火等材料的塡料，還可用來配製有機樹脂類黏合劑。

爐底灰在性質及化學成份上與煤灰相似，只是顆粒較粗，直徑由30毫米至50微米以下。

Typical constituents of China Light's PFA and of Ordinary Portland Cement. *中電煤灰及普通水泥典型組份*

Constituents		PFA to BS3892		OPC
		Normal Range	Typical Value	Normal Range
Silica	SiO_2	38 – 77	54%	18 – 25%
Alumina	Al_2O_3	14 – 46	29%	4 – 7%
Iron Oxide	FeO_3	1.2 – 18	5%	1 – 4%
Calcium Oxide	CaO*	<0.1 – 16	5.1%	64 – 68%
Magnesium Oxide	MgO	<0.1 – 2.6	1%	0.5 – 3.5
Alkalis	Na_2O & K_2O	<0.1 – 2.5	1.3%	0.2 – 0.8
Sulphuric Anhydride	SO_3	<0.1 – 0.8	0.6	3.0%
Chloride	Cl	–	<0.1%	–
Loss On Ignition	(LOI)	3.5 – 6.0	5%	4%
Moisture Content	(H_2O)	–	<0.1%	–

FBA, Cenospheres and PFA. *爐底灰，煤胞及煤灰粉*

PFA in Concrete

PFA can also be used as a pozzolana, a term encompassing a class of natural and artificial minerals that produce, in combination with lime and water, stable cementitious compounds. PFA can, therefore, be used widely in insitu concrete and precast products where it offers a wide range of benefits, of which one of the most significant is durability.

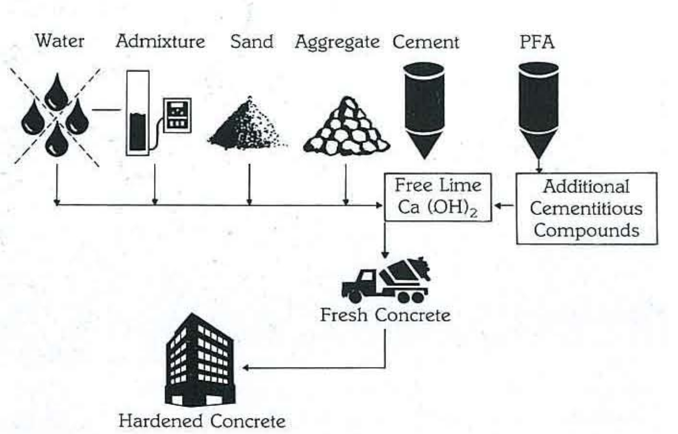
In Hong Kong, hundreds of projects have incorporated PFA either as a separate cementitious component or in a blended Portland/PFA cement mix manufactured locally.

Three properties are mainly responsible for the beneficial effects which have led to the growing use of PFA in concrete:

- Ability to combine with free lime (pozzolanic activity)
- Rounded particle shape
- Reduced water demand

When cement hydrates, free lime is released and this can subsequently be washed out of the concrete, rendering the concrete less durable. The ability of PFA to combine with the free lime released during hydration of cement to form additional cementitious compounds is termed the pozzolanic reaction. Advantage has been taken of this reaction for many years by using PFA to replace part of the cement in concrete.

The action of PFA on concrete. 煤灰在混凝土中的作用



PFA is mandatory in concrete for roads. 煤灰粉是道路混凝土必不可缺材料

Placing PFA concrete in pile heartings. 樁中澆築煤灰粉混凝土

混凝土中煤灰料

煤灰性質近似火山灰。火山灰是天然及人造礦物混和石灰、水，化合而成穩定的粘結性硬化合物，煤灰可廣泛用於現場澆注混凝土作業及預製混凝土件作業。煤灰優點衆多，其中最重要的是它的耐用性。

本港數以百計的建築工程，經已採用煤灰水泥替代部份水泥，或就地採用本港自拌的煤灰/普通混合水泥。

煤灰在工業用途中起重要作用，因其具備以下特性：

* 與生石灰化合（硬結性）
* 渾圓粒型
* 用水量低

混凝土與水混合後，放出生石灰，易被沖走，故不耐用；煤灰能與水泥水化所放出的生石灰化合，增加膠結性化合物，稱爲火山灰硬結反應。多年以來，此項反應已被利用，改用煤灰取代部份水泥，作爲混凝土料。

煤灰用作膠結性輔料，具有各種技術優點，如表所示。如用煤灰取代部份水泥，早期強度較差，但配以適當配料比例設計，仍可容許在較短時間內拆除模板。

煤灰的球狀顆粒，拌合角狀的水泥及碎石，可以提高混凝土的施工性能，配成的混凝土密實度往往較高，加上煤灰顆粒的充填作用，使混凝土體質更加緊密，從而加強對硫酸鹽及氯化物等腐蝕性化學品的抗蝕性。

因此，煤灰尤其有利於本港之海洋環境，適合海洋工程及地下作業。

The Kwai Chung Road Flyover used PFA concrete. 煤灰混凝土用於葵涌道天橋

PFA concrete in the Route 5 tunnel linings and roads.
煤灰混凝土用於5號公路隧道襯壁及道路

The use of PFA as a supplementary cementitious material can produce various technical benefits, as illustrated in the table. While simple partial replacement of cement by PFA may result in reduced early strength, this can be eliminated by proper mix design, to allow shutter stripping at very early ages.

The inclusion of PFA as a cementitious component has been shown, by worldwide research, to improve the long-term strength and durability of concrete, by virtue of the pozzolanic reaction.

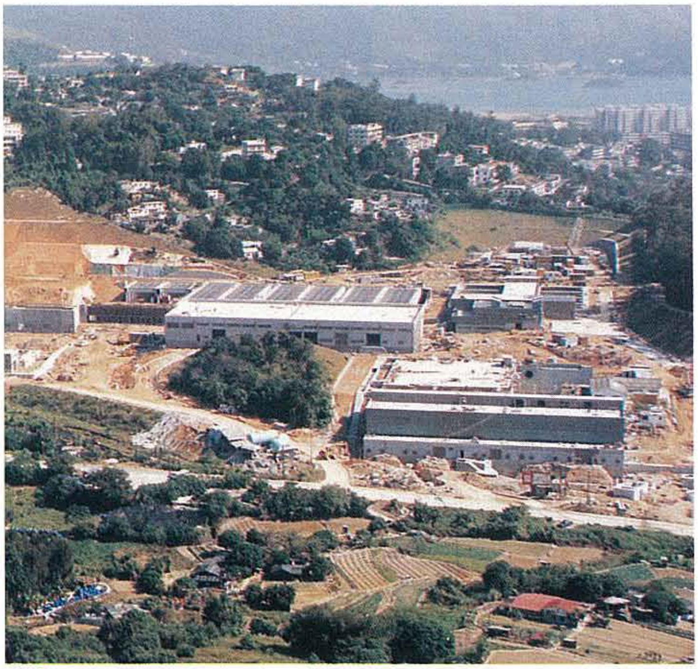
The rounded particles in PFA can improve the workability of concrete when mixed with the more angular shapes in cement and in crushed rock aggregates. This effect generally reduces segregation and bleeding and produces easier compaction of the concrete. Together with the filling effect of the PFA particles, it usually produces a more densely packed concrete which is more resistant to aggressive chemicals such as sulphates and chlorides.

PFA can be particularly beneficial, therefore, in marine environments such as Hong Kong's, and in marine works and below ground applications.

- Cost savings
- Improved workability
- Reduced bleeding
- Lower heat of hydration
- Reduced cracking
- Greater cementitious content
- Higher long-term strength
- Long-term durability
- Reduced permeability
- Resistance to abrasion
- High chemical resistance
- Improved resistance to ASR

There is growing interest by cement manufacturers worldwide in producing blended Portland/PFA cements. These can be made either by intergrinding PFA with cement clinker or by dry blending, processes currently used by Hong Kong cement manufacturers.

The relative advantages of using either blended cements or adding PFA at the concrete mixer will depend mainly on the cost, type of concrete and the quality of cement.

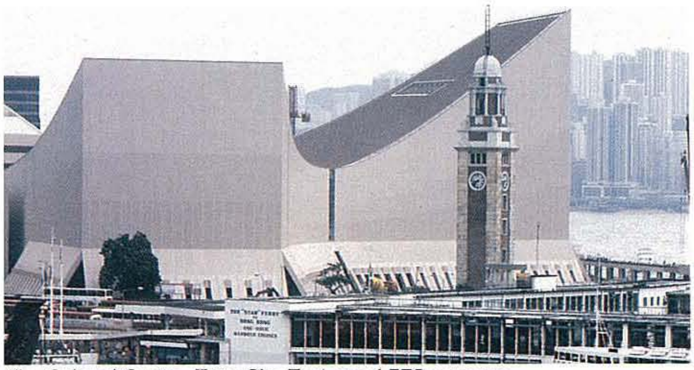


PFA concrete was used in the Pak Kong Water Treatment Works.
北港濾水廠工程採用煤灰混凝土

以施工性能同等的混凝土而論，煤灰拌水用量通常低於普通水泥。新澆混凝土用水少，可以防止出水等現象，並提高強度及耐用性。

世界水泥廠商現時採用的方法，爲煤灰及水泥溶渣研磨法及乾拌法。

使用煤灰水泥或煤灰直接加入混凝土攪拌機使用，孰優孰劣，主要取決於成本，混凝土產品種類及水泥的品質。



The Cultural Centre, Tsim Sha Tsui, used PFA concrete.
採用煤灰粉混凝土的尖沙咀文化中心

PFA concrete for the Eastern Harbour Crossing immersed tube units.
煤灰混凝土用於東區海底隧道的海底管道

Construction of the Harbour Road Government Offices using PFA concrete.
煤灰混凝土用於建築港灣道政府合署

Precasting and Concrete Products

PFA and FBA are used in the manufacture of concrete products to produce higher strength and lighter weight building materials at reduced cost. Producers in Hong Kong and Shenzhen consume about 250,000 tonnes of ash per annum for this purpose.

Paving units incorporating ash. 摻粉舖面

In building blocks and pavers, FBA and PFA offer many benefits: improved casting operations, improved surface finish and reduced weight. Aerated structural blocks, which can be cut, sawn and nailed, are manufactured from a foamed PFA/cement slurry. The resulting blocks are very light and have low thermal conductivity.

In addition to building blocks, PFA can be used both as part of the cementitious material and as an aggregate in numerous concrete products such as concrete roof tiles, kerbs, edgings and flags, paving units, concrete pipes, concrete bricks, concrete lintels, lamp posts, and tunnel lining segments.

PFA can also provide improved durability through resistance to aggressive environmental and chemical conditions and can give a better surface finish. Thus, for example, the 3 million tonnes of concrete tunnel lining segments for the Channel Tunnel connecting England and France incorporate PFA as 30% of the cementitious material, in what is one of the world's largest precasting operations.

Precast PFA concrete piles. 預澆煤灰混凝土樁

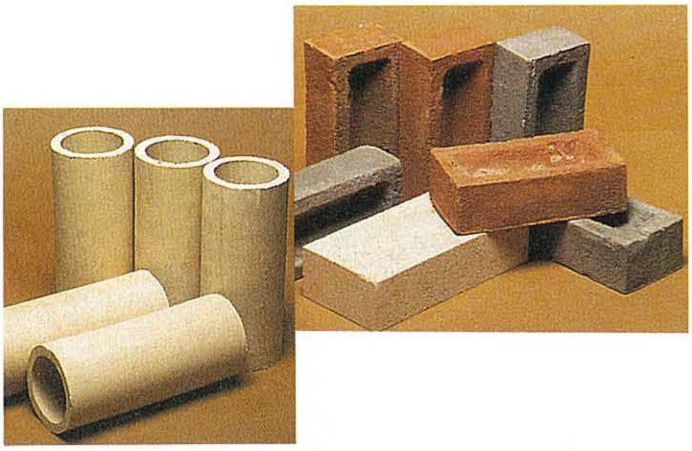
混凝土製品

混凝土材製造中採用煤灰或爐底灰，可以減低成本，製造出強度高、質量輕建材。香港、深圳兩地每年使用25萬噸左右煤灰用以製造此類建材。

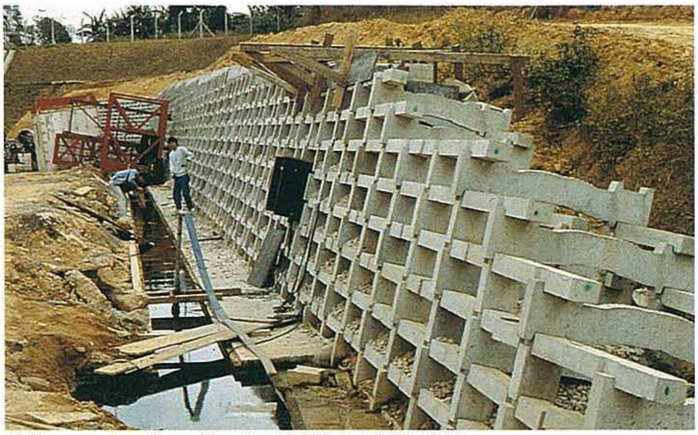
煤灰及爐底灰於製成空心磚及路面磚時優點甚多：可以改善澆注作業，表面較光滑及重量較輕。用有泡之煤灰/水泥漿製成之空心磚可以切斷，鋸開及釘穿孔。此種空心磚甚輕，傳熱性低。

除空心板塊外，煤灰可以兼作膠性結材及骨料，用於混凝土屋面磚、路石、路邊石、路面舖砌材、混凝土管、混凝土磚、混凝土楣，燈柱及隧道管道襯面等多種混凝土製品。

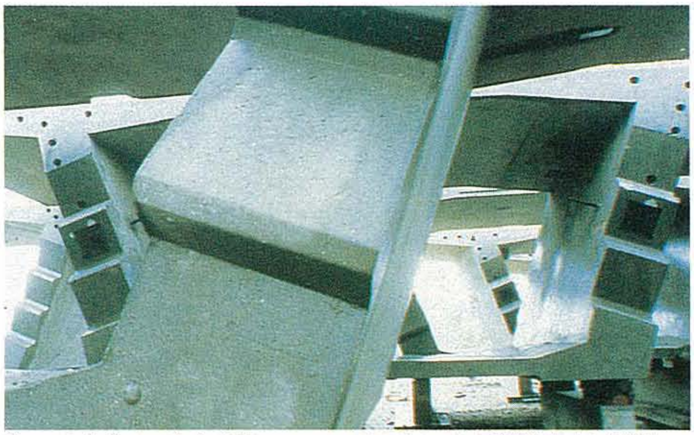
煤灰對於侵蝕性的環境具有抗蝕性，故有較佳的耐用性及表面光滑度。英倫海峽海底隧道中的三百萬噸混凝土襯面構件即爲一例，膠結料中煤灰佔30%，是世界最大預製件工程之一。



PFA and FBA used in pipes, bricks and blocks.
煤灰及爐底灰築管道、砌磚及舖磚



PFA concrete crib wall units. 煤灰混凝土預澆早橋段



Precast viaduct units in PFA concrete. 用粉煤灰混凝土預裝仲築成架空管道

Lightweight Aggregates

There are several uses for lightweight sintered or cement-bound PFA aggregates. These include use in the structural concrete of multi-storey buildings, in precast structural cladding panels, lightweight floor screeds and in concrete blocks. Concretes based on sintered or cement-bound PFA aggregates have only about two-thirds the weight and twice the effective thermal insulation of equivalent gravel aggregate concrete.

Major structures, such as the National Westminster Tower in London, have benefited from the advantages of lightweight PFA aggregate. The application of this material in Hong Kong is being evaluated.

輕質骨料

輕質煤灰經高溫溶結或與水泥拌合骨料，用於多層高樓結構混凝土材，預製結構包鋼面板，輕質樓面板和混凝土空心磚材等，基於以高溫溶結或水泥拌合骨料的混凝土對比同等的礫石骨材混凝土，重量只有三分之二，有效隔熱性則高一倍。

英國倫敦西敏銀行大厦等大型建築物，亦得益於輕質級煤灰骨料。本港現正考慮輕質骨料的本地用途。

Lightweight aggregate blocks.
輕質骨料舖磚

The National Westminster Tower, London, used lightweight PFA aggregate.
倫敦輕質骨料建築的英國西敏銀行大厦

Grouts and Slurries

Due to PFA's predominantly spherical particle shape, fine grading and the relative ease with which the material can be put into suspension, together with its pumpability and reduced segregation, it is an effective answer to many grouting problems.

Examples of the use of PFA grouts and slurries include cavity filling in abandoned tunnels, sewers and ground voids, structural fills and trench backfills, curtain walls around foundations and under water-retaining structures and in strengthening embankments, railway tracks, bridge abutments and other structures. PFA grouts are also used to form protective mattresses and to repair brick and masonry structures such as bridge piers, railway tunnels and culverts.

The slurry cut-off wall at Tsang Tsui used a PFA/cement/bentonite mix.
煤灰／水泥／斑脫土築曾咀阻隔火牆

PFA Mortars

PFA mortars are used worldwide for rendering, waterproofing and structural repairs as they offer good cohesion and workability and allow high build. In Hong Kong, PFA mortars are used for repair of housing blocks and other buildings. They can be used in bagged form or ready-mixed delivered to site.

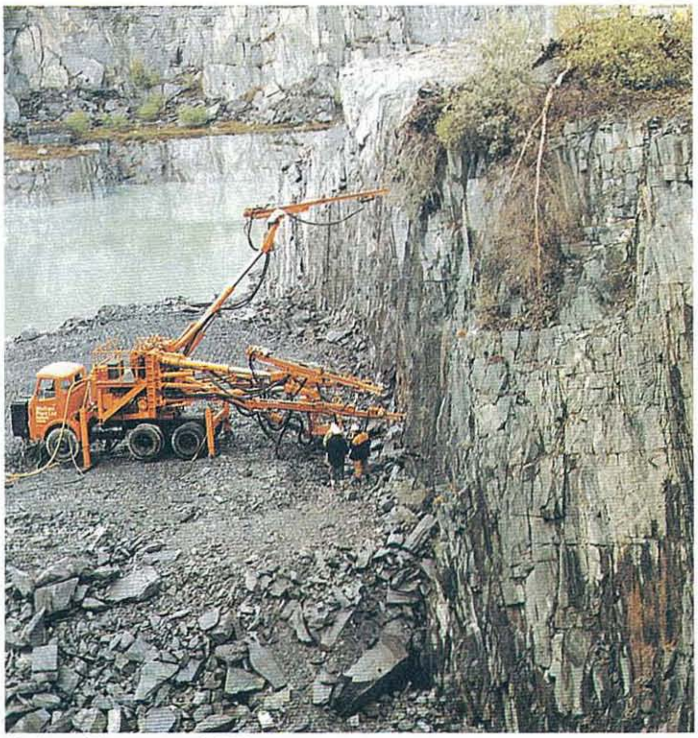
Refurbishment of army huts with PFA mortar.
用煤灰漿翻修軍隊營房

灌漿及水泥漿

煤灰顆粒以球形爲主，粒度幼細，較易轉爲懸浮態，不易離析及可由泵抽出，故可有效解決許多灌漿問題。

煤灰灌漿用途廣，例如填平棄水道的凹下水道穴及地上洞孔，結構填料及溝渠填料，地基幕牆及擋水結構基底、加固堤岸、鐵路路基、橋台等其他結構，煤灰漿更可發揮保護褥的作用，以修補橋墩，鐵路隧道，涵洞等磚石結構。

Construction of a PFA concrete watertight membrane.
煤灰混凝土築隔水牆



Rock stabilisation with PFA grouts.
用煤灰漿鞏固岩縫

煤灰灰漿

煤灰灰漿由於其內黏性、施工性好、可進行高空作業，全世界各地的用途有抹灰、舖設防水面及結構維修。本港現正使用煤灰灰漿，修築屋邨與及其他建築物，成效斐然。灰漿有袋裝亦有現拌裝送往地盤。

Cement Stabilised PFA

A mixture of PFA and cement mixed with an appropriate amount of water forms a strong, hard material when compacted properly. These mixtures have been in continuous use worldwide for some years as hardstandings for heavy industrial and agricultural storage, road bases and sub-bases, bridge abutments and similar structures where lean concrete and similar materials are traditionally used.

Cement stabilised PFA normally contains about 5%to10% cement, depending on the application.

Flowable PFA

Flowable PFA is a cement stabilised backfill material mixed with water and admixtures to make the mixture fluid. It can be used to form a lightweight, structural fill in water or on land, and flows into place without spreading, rolling and compacting. Its properties are significantly better than those of conventional structural backfill materials, and strengths can be adjusted from 1 to over 20 MPa.

水泥加固煤灰料

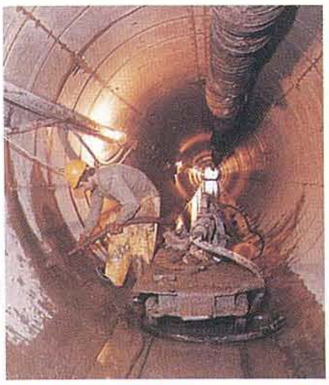
煤灰及水泥混合料用適量水拌和，再經壓實，成料堅硬牢固，舉世廣泛採用多年，取代慣用的淡混凝土，作爲工農業重型倉庫、路基及副基、橋墩等結構的底基。

水泥加固煤灰料中，一般含有5%至10%左右的水泥，視用途而定。

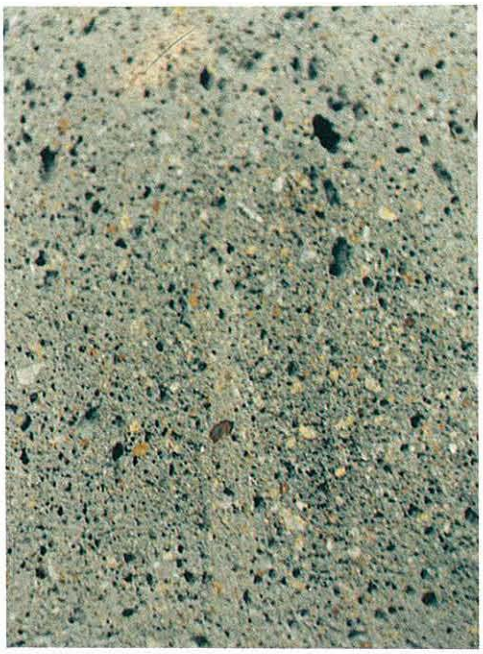
流動煤灰料

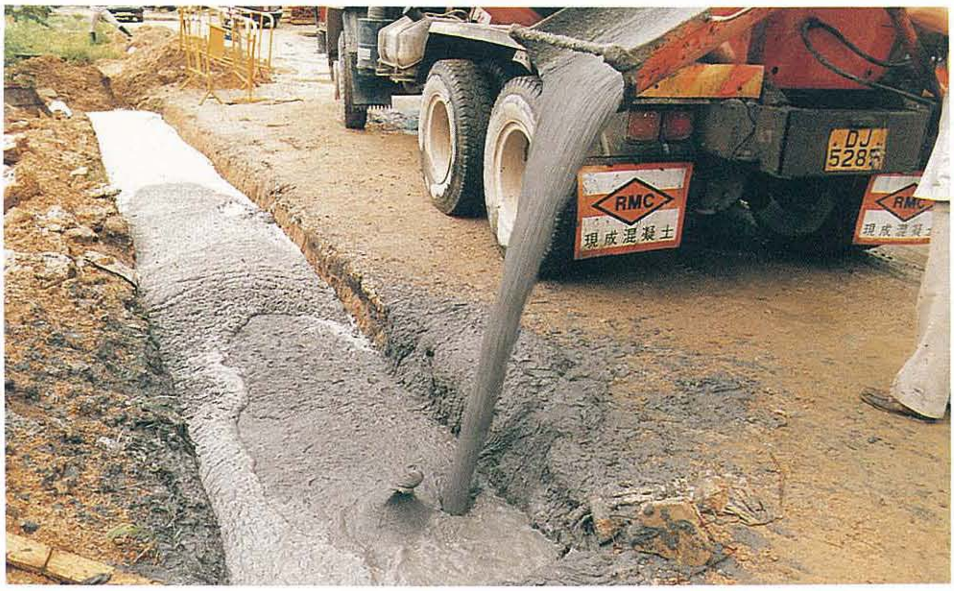
煤灰水泥中加進適當的水及添加劑，便成爲一種水泥加固回填料，可以用作水陸結構輕質填土，自流舖築，無需攤開、碾平及壓實，性質遠較普通結構回填料爲優，強度可由1調至20兆帕（Mpa）以上。

Flowable PFA fill, using 5% cement and seawater, had a strength of 1 MPa at 1 day.
煤灰配拌5%水泥的海水流動填料一天强度高達1兆帕



Tunnel grouting with PFA.
煤灰漿築隧道





Foamed PFA fill (left) can be placed in water and can be designed to achieve strengths from 1 to over 20 MPa (above)
（圖左）煤灰泡沫填料可作水下澆築，設計强度高達1至20兆帕（圖上）

PFA for Fill and Reclamation

When moist PFA is properly compacted in layers of appropriate thickness, it forms an excellent load-bearing fill. PFA can also be placed in water as a lightweight reclamation fill. Many millions of tonnes have been used as a fill in various types of construction worldwide.

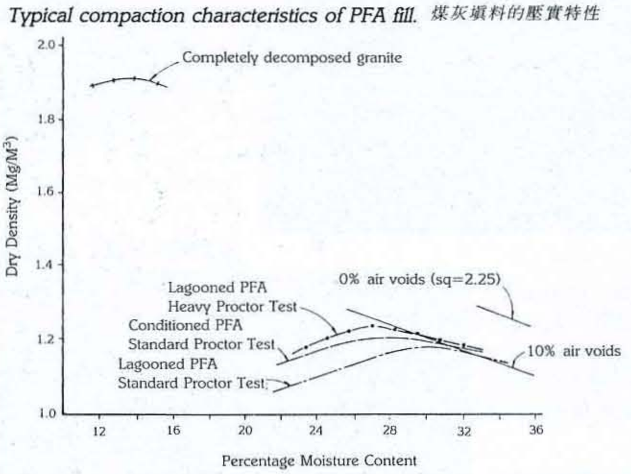
More than 2 million tonnes of Hong Kong-produced PFA have been used as fill in Hong Kong, Macau and China for the formation of over 40 hectares of land for high-rise development and other uses, much of this in marine and marsh reclamation.

The properties important to PFA's performance as a robust and stable fill are:

- Light weight
- High shear strength
- Low compressibility
- Self-hardening properties

The compacted bulk density of PFA is generally between 1400 and 1700 kg/m^3 (dry density 1100 to 1300 kg/m^3), which is less than that of most conventional fill materials. Road embankments and land reclamations built with PFA are therefore relatively light in weight, an important advantage on ground or seabed conditions of poor load-bearing capacity.

Typical compaction characteristics of PFA fill. 煤灰填料的壓實特性



The low bulk density and high internal strength of PFA also reduce horizontal forces on retaining walls and bridge abutments, which can thus often be designed more economically.

When used as a fill for marine or land reclamation, PFA rapidly consolidates to form a stable, settlement-free platform for construction.

Precast concrete and steel piles can be driven through compacted PFA. Foundation and utility trenches excavated in PFA remain stable, even in wet weather, with the minimum of shoring.

Three types of PFA can be supplied by truck or barge for use as fill:

1) Conditioned – freshly produced PFA with water added to assist compaction.
2) Lagoon – PFA recovered from ash lagoons and supplied in similar form to conditioned PFA.
3) Stockpiled – temporarily stored material consisting of conditioned PFA.

煤灰填料

濕煤灰經壓實，形成厚度適中的優良承載填料。世界各國用此作爲建築填料，逾百萬噸計。

港、澳及中國迄今使用二百五十多萬噸港產煤灰，填海築地40多公頃，供興建多層大厦用，有不少位於瀕海或沼澤地區。

煤灰作爲填料，結實穩定，主要由於重量輕，剪切強度高，壓縮性低，及其自動凝固性。

煤灰壓實後的比重一般是1.4至1.7，低於常用填料。煤灰所築路堤及填海地段因而較輕，承載力差的地面或海床尤其適用。

煤灰重量輕，內強度高，使護土牆及橋墩水平壓力減少，工程成本也因此降低。

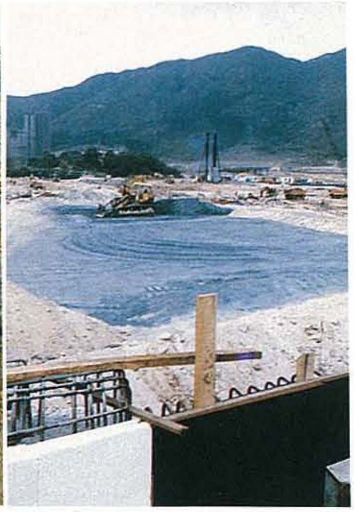
煤灰用作海陸填料，容易顆結成塊，使填築地穩定無沉降現象。

預製混凝土樁及鋼樁，可輕易打穿壓實的煤灰層。煤灰地基及公用事業開挖之地下管坑道，可耐潮濕季候，堅實穩定，不大需用支撐。

貨車或駁船供貨之煤灰填料共有三種：

* 調濕料－現產煤灰加水以助壓實
* 湖灰料－取自煤灰湖，供應方式同調濕料
* 庫存料－暫時堆放的調濕煤灰

Foundation excavation through PFA fill for Tuen Mun housing blocks.
屯門屋邨地基煤灰填地開掘工程



PFA fill for road embankments in Tuen Mun.
屯門煤灰填築路堤

Marsh reclamation at Ha Tsuen, New Territories
新界夏村沼澤填地工程

Loading conditioned PFA into a lighter barge. 用輕駁船裝載濕煤灰

Marine reclamation for the Eastern Harbour Crossing using PFA as a lightweight fill. 東區海底隧道填海區使用煤灰作爲輕質填料

Excavation of PFA fill 5 years after placing. 煤灰塡地澆築五年之後開挖情景

Reclaiming fish ponds near Hung Shui Kiu, New Territories.
新界洪水橋魚塘塡地

Typical operations at a PFA fill site.
煤灰塡築地盤施工情景

Ash in Highways

Both PFA and FBA can be used in highway construction. The use of PFA in pavement quality concrete is now mandatory in Hong Kong roads due to the improved strength and abrasion resistance provided. Conditioned with water, PFA is also suitable for constructing highway embankments, backfilling utility trenches and building capping layers over weak foundation materials such as those prevalent in the New Territories.

FBA is an ideal road base material because it is easy to handle and compact, and can be placed in all weather conditions. A free draining, granular material, FBA protects the subgrade against inclement weather and construction traffic.

Site trials of stabilised PFA confirmed its suitability for highway use.
公路地盤煤灰穩固後適用性測試，証明適合作爲公路路基填料

PFA in Reinforced Soil Structures

Reinforced soil is a technique being used increasingly for building retaining walls on difficult sites as an alternative to otherwise costly piling and massive concrete retaining walls.

When used in conjunction with polymer reinforcement, PFA's characteristics of being a lightweight load-bearing fill with reduced internal stress, plus its self-hardening properties are very well suited to this technique.

Long-term tests in the UK indicate that normal corrosion allowances for steel embedded in granular fill are also adequate for PFA.

PFA and polymer grids for reinforced soil applications.
煤灰及塑膠網強化土壤

PFA concrete in elevated highway structure.
煤灰混凝土構築高架公路

FBA used for hardstanding.
煤灰築停機坪

煤灰用於公路

煤灰及爐底灰均可用於建築公路。

因煤灰提高混凝土強度及耐磨性，本港現已規定鋪路用之混凝土必須加入煤灰。煤灰加水調濕，亦適宜建築路堤，回填水管電纜坑道，填築蓋層，以加固新界常見之薄弱地基。

爐底灰易於處理壓實，一切氣候條件均可澆築，故爲理想築路基料。爐底灰呈粒狀，疏水性能高，保護路基，免受惡劣天氣及建築工程車輛所損壞。

PFA road embankment in Tuen Mun. *屯門煤灰路堤*

固土結構煤灰料

在地盤上建築護土牆，經常採用固土技術，取代造價高昂的打樁工程及大面積的混凝土護牆。

煤灰同塑膠網組合，利用煤灰削減內應力作爲有承載力的輕填土料，容易沉降固實，尤其適合固土技術之需。

在英國長期試驗後證明嵌粒狀填料的鋼筋若嵌入煤灰填料時其抗腐蝕度合符英國的標準。

PFA in Water Treatment

PFA can be treated with caustic soda and hydrochloric acid solutions to remove some of its iron, alumina and silica. The products of this process comprise a caustic leachate, an acid leachate and an acid residue.

The caustic leachate can replace lime in water treatment processes for pH control. The acid leachate can be used as a coagulant. The acid residue can be used as additive to sludge to improve the dewatering process.

PFA in Waste Treatment and Disposal

One of the methods of dealing with toxic and hazardous wastes is by chemical stabilisation, including techniques using cement or lime and a pozzolanic material.

Waste stabilisation using cement or lime and employing PFA as a pozzolan have been successfully developed in a number of applications, with a wide range of waste products.

PFA can also be employed, using appropriate handling methods, as a cover material for refuse tip management.

Site trials of PFA/ bentonite for use as a refuse tip liner material.
垃圾堆放現場上試用PFA／斑脫土作上蓋內襯。

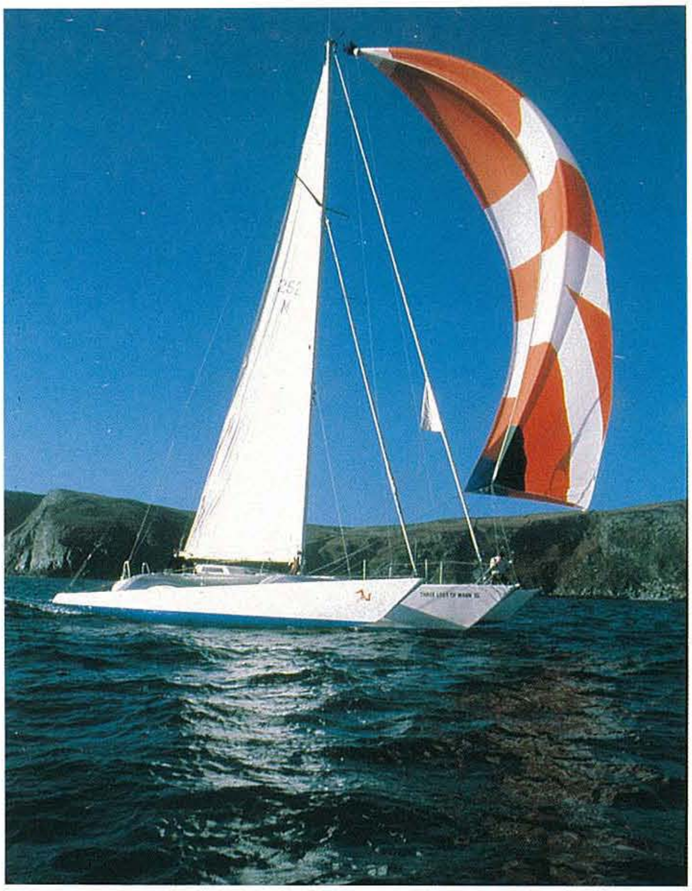
PFA Cenospheres

These microspheres float to the surface of the water when ash is pumped from the power station into lagoons as a slurry. They have the same chemical composition as the remainder of the ash and differ only in that they have a specific gravity of less than 1. In their untreated state, cenospheres (commonly called floaters) range in size from 1 to 400 microns.

Ski poles incorporating cenospheres.
煤胞製滑雪杖

Their unique properties are utilised for a diversity of applications due to their being inert, acid resistant and light in weight. Floaters can give up to four times the filling capacity of most other fillers and can also give improved thermal and electrical properties.

In the construction and building industries floaters are used in a wide variety of applications including lightweight concrete, fire screens, roof tiles, PVC window frames, insulation panels and window putty. Floaters are also incorporated in plastics and other materials for a variety of applications where strength and light weight are important.



Cenospheres are used in paints and plastics. *煤胞製漆及塑膠*

食水處理

經碱及鹽酸溶液處理後，可以除去煤灰中的鐵、礬土、矽等成份，溶出碱性鹽、鹽酸性鹽及酸渣。

碱性鹽在食水處理過程可代石灰以控制酸碱值；酸性鹽可作凝結劑，酸渣可作淤泥脫水添加劑。

廢物處理

處理有毒有害廢物時，可用化學穩定法，其中可使用水泥、石灰及火山灰料。

採用水泥或石灰，並以煤灰作爲火山灰料去處理及穩定廢物成效超卓，此方法並可用作處理多種不同廢料。

煤灰如能妥予處理，也可作爲垃圾堆上覆蓋料。

煤灰灰胞

煤灰加水後成爲煤灰漿，由電廠泵送至煤灰湖，途中會有微球煤胞浮出水面。它的化學成份和煤灰一樣，只是比重小於1。未經處理的煤胞粒大小由1至400微米。

浮胞具有惰性，耐酸及輕質等特性，可作各種用途。浮胞填充合力是其他大多數填料的三倍，有更佳隔熱及絕緣的能力。

浮胞在樓宇建築業中，用途廣泛，包括用於製作輕質混凝土、防火網料、屋面磚、PVC窗框、絕緣板及玻璃窗油灰。塑膠及其他材料，若講求高強度或輕便，一般都摻進浮胞。

Ash in the Landscape

Conditioned PFA, FBA and lagoon ash are amendable to planting and landscaping.

The results of China Light's ongoing horticultural studies indicate that a wide range of common Hong Kong species, such as grass, shrubs and trees, can be grown directly onto PFA and mixtures of PFA/soil and PFA/organic matter.

Selected root and cereal crops can be safely grown on weathered PFA and grass grown over PFA can provide satisfactory grazing for cattle and other animals.

PFA can be used to improve both sandy and heavy clay soils. For planting on PFA, a layer of soil of 100mm or so is commonly placed over the PFA to accelerate root formation and, where feasible, mixing of this layer into the PFA is beneficial.

景觀工程

調濕煤灰、爐底灰及湖灰，可作綠化種植之用。

中電現時園藝研究結果表明，本港常見之灌木、草、樹木大多可在煤灰，泥土及有機物等混合土中直接生長。

多類植物，尤其是生果類植物，可在煤灰中安然生長，煤灰上種草可飼養牛以及其他動物，效果頁好。

煤灰可以用來改善沙質及高粘土土壤。在煤灰上種植草木，灰面上鋪100毫米土層可促使根部成長；如情況許可，將土層拌入煤灰內，亦可產生頁好效果。

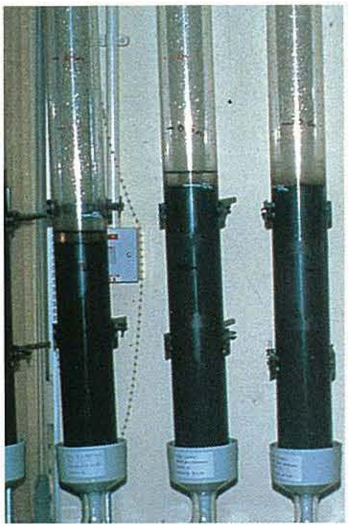
PFA horticultural trials at Castle Peak Power Stations (above and below).
青山電廠用煤灰作園藝試驗(上、下)

Landscaping of PFA fill in progress (above) at Siu Lang Shui and (below) the completed embankment face after grassing and tree planting.
小冷水煤灰塡地築園情景（上）鋪草植樹後路堤全景（下）

Environmental Considerations

Despite the almost inert nature of PFA, environmental considerations are given high priority by China Light. Routine air and water monitoring of projects incorporating large quantities of PFA in applications such as bulk fill indicate that there are no significant environmental concerns associated with its use.

Tests to date both in Hong Kong and abroad conclude that the radiological and occupational health aspects of PFA are not significantly different from those of other commonly used building products and bulk fills such as the granite soils and aggregates used in Hong Kong.



Leachate tests being undertaken at China Light's laboratory.
中電化驗室內煤灰礦物溶出試驗

Environmental monitoring station at the Tsang Tsui ash lagoons.
曾咀煤灰粉湖環境監測站

Mobile dust monitoring equipment in use at a PFA fill site.
煤灰填區之流動塵土監測設備

Oyster monitoring programme near the Tsang Tsui ash lagoons.
曾咀煤灰湖附近蠔場監察計劃

環境影響

中電非常重視煤灰對環境的影响。對使用煤灰項目，特别是對使用了大量煤灰作大面積填料用的工程項目，進行了空氣及水質監測，結果顯示，對環境不致造成影响。據目前在本港及海外的測試所知，煤灰在輻射及職業安全方面和常用建材填料一樣，並無任何差異。

Acknowledgements

The assistance of the following organisations in the preparation of this brochure is gratefully acknowledged:

Clients:

Architectural Services Department, Hong Kong Government ● Castle Peak Power Company Limited ● Highways Department, Hong Kong Government ● New Hong Kong Tunnel Co Ltd ● Territory Development Department, Hong Kong Government ● Urban Council ● Water Supplies Department, Hong Kong Government

Consultants/Designers:

Acer Consultants (Far East) Ltd ● Binnie Consultants Limited ● Ho-Happold Consulting Engineers ● L G Mouchel & Partners (Asia) ● Maunsell Consultants Asia Ltd ● Mott MacDonald Hong Kong Ltd ● Oakervee Perrett (Asia) Ltd ● Scott Wilson Kirkpatrick & Partners ● Watson Haswell

Contractors/Project Managers:

Aoki Corporation ● Costain International Ltd ● China State Construction Engineering Corporation ● Gammon – Dragages – Skanska Joint Venture ● EHC Project Management Co Ltd ● Franki Kier Ltd ● Kin Ching Besser Co Ltd ● Kumagai Gumi Co Ltd ● John Lok & Partners ● Maeda Corporation ● Shui On Civil Contractors Ltd ● Shun Shing Construction & Engineering Co Ltd ● Tobishima Corporation

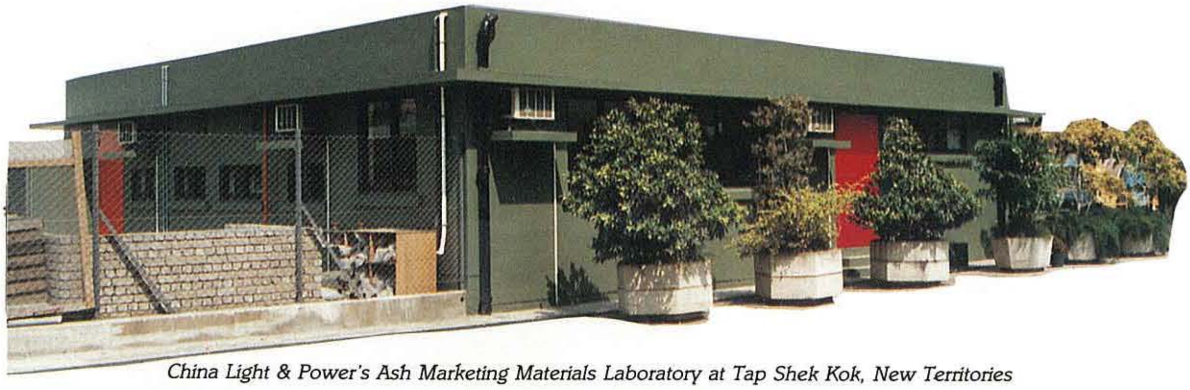
Concrete Suppliers:

Gammon Construction Ltd ● K Wah Concrete Ltd ● Ken On Concrete Co Ltd ● Pioneer Concrete (Hong Kong) Limited ● Ready Mixed Concrete (HK) Ltd

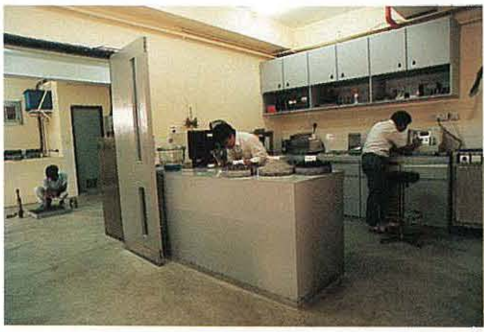
PFA Suppliers:

China Cement Company (Hong Kong) Ltd ● China Light & Power Co Ltd – Ash Marketing Branch ● Kin Ching Ash Ltd ● Lamsonite Company Ltd

Grateful acknowledgement is also given to National Power, UK (formally Central Electricity Generating Board) for permission to use several of their photos showing the use of PFA in England.



China Light & Power's Ash Marketing Materials Laboratory at Tap Shek Kok, New Territories
中電新界塔石角煤灰粉料化驗室



Technical Assistance

This brochure has briefly described the properties and applications of ash and the benefits ash has to offer Hong Kong.
A series of technical leaflets and bulletins is available providing more comprehensive information on ash for specific applications.
Please contact China Light & Power, Ash Marketing Branch, for details of literature available and for assistance whenever ash is being considered for a project.

技術協助

本文介紹了煤灰的性質用途與及煤灰可爲本港帶來的益處，
中電現備有多種有關煤灰技術的小冊子供索閱，詳述煤灰各種特別用途，有意查詢採用者，
請與燃料供應部煤灰銷售支部聯絡，當予協助。

China Light & Power Co., Ltd.
中華電力有限公司 Ash Marketing

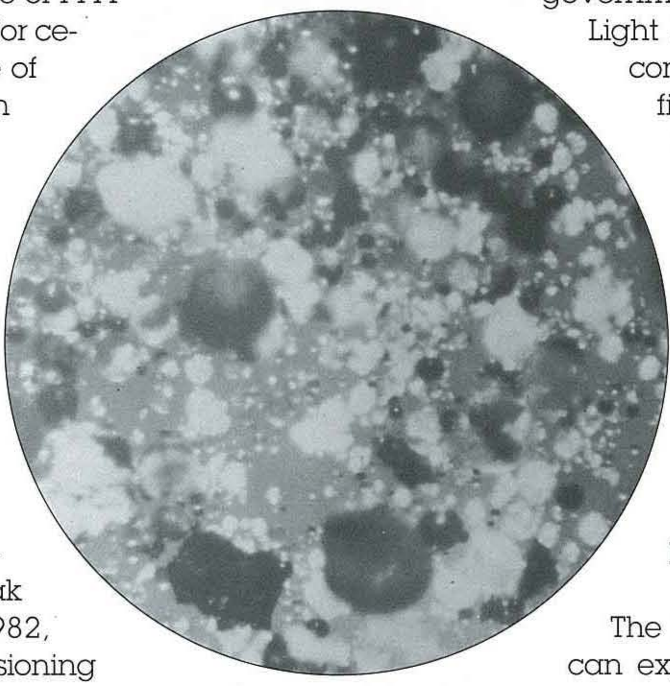
147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

PFA

Pulverized Fuel Ash

For a better quality concrete

FOR nearly a decade, China Light & Power Co Ltd has been actively promoting the beneficial utilisation of Pulverized Fuel Ash (PFA) in structural concrete and in other applications. The company's efforts recently received a major boost when both the Works Branch and the Building Authority of the Hong Kong Government issued revised practice notes allowing greater use of PFA as a partial replacement for cement in the manufacture of structural concrete used on contracts under their control.



PFA — or 'fly ash' as it is known internationally — is the residual byproduct of the pulverized coal burnt in the furnaces of modern electricity generating stations. China Light & Power has been producing PFA at its Castle Peak Power Stations since 1982, when progressive commissioning of the stations commenced. Over the years, some of the company's PFA has been sold to the construction industry for use in concrete and as a fill material. Surplus PFA has been stockpiled in specially constructed lagoons at Tsang Tsui.

Major Hong Kong projects on which PFA has been used as a partial cement replacement in structural concrete include the Harbour Road Government Offices, the Tsim Sha Tsui Cultural Centre, the Pak Kong Water Treatment Works, Route 5, the Eastern Harbour Crossing and the Tsing Yi North Bridge.

The positive steps recently announced by the Works Branch and the Building Authority were based on valid technical environmental and economic grounds. In view of the increased usage of PFA that will result from the new government practice notes, China Light & Power is planning the construction of an ash classification plant. This plant will produce PFA to BS 3892: Part 1, the most stringent standard regulating the use of PFA as a partial cement replacement in concrete.

Socio-Economic and Technical Benefits of PFA

The Hong Kong community can expect a number of socio-economic benefits from the greater use of PFA, particularly as a partial replacement for cement in structural concrete. Paramount amongst these are the:

- Utilisation of one of Hong Kong's few genuine resources;
- Elimination of the environmental problems associated with costly disposal;
- Maintenance of stable electricity prices;
- Savings of several hundred million dollars

Ref : WB(W) 209/32/31 (89) IV

WORKS BRANCH
GOVERNMENT SECRETARIAT
MURRAY BUILDING
GARDEN ROAD
HONG KONG

24 September 1990

Works Branch Technical Circular No. 14/90

The Use of PFA in Structural Concrete

Introduction

The Lands and Works Branch Practice Note No. 4, The Use of PFA in Structural Concrete, was issued in 1983. The attached addendum sets out the current position on this subject and should be added to the Practice Note.

Action to be taken

For the reasons stated in the addendum, all engineers and architects and consultants responsible for specifying concrete or for approving contractors' proposals are required actively to encourage the use of PFA as a cement replacement material. For thick sections, high strengths, where shrinkage and cracking are critical, where resistance to sulphate attack is required and where surface finish is particularly important, PFA concrete should be specified.

The current General Specification for Concrete for Structures, promulgated with LWB TC 16/83, should be amended to delete the requirement for the Engineer's/Architect's approval to the use of PFA. Should there be special circumstances where the use of PFA is considered undesirable, the project engineer/architect shall seek the approval of the Works Branch Standing Committee on Concrete Technology to include a restricting Particular Specification clause in the contract.

Any queries on this subject should be addressed to the Standing Committee on Concrete Technology.

(R H Pilling)
Deputy Secretary (Works Policy)

Works Branch Technical Circular 14/90

BUILDINGS ORDINANCE OFFICE — PRACTICE NOTE FOR AUTHORIZED PERSONS AND REGISTERED STRUCTURAL ENGINEERS — 90

The Use of Pulverised Fuel Ash in Concrete

Where Pulverised Fuel Ash (PFA) is used as a partial cement replacement in concrete, the properties of such concrete may differ from those made with conventional materials and the characteristics of the concrete may be altered, in particular its slower rate of strength development. Consequently, the performance of concrete made with PFA, and its suitability for the purposes required should be established.

2. Use of such concrete may be permitted on a project basis if it can be established that the performance of the concrete is satisfactory and the control on site is adequate. In this respect the authorised person/registered structural engineer should ensure that the following requirements are complied with:

(a) The PFA should comply with BS 3892:Part 1:1982 except that the criterion for maximum water requirement may not apply.

(b) PFA should only be used with Ordinary Portland Cement.

(c) The PFA content should not exceed 25% by mass of the cementitious content (total cement plus ash).

(d) The extent of the use of the PFA concrete and the specification for materials, curing and removal of formwork should be given on the plans submitted for approval.

(e) A satisfactory quality assurance proposal should be submitted. The proposal should include particulars of the source and testing of the PFA, details of mix design, and provisions of qualified supervision and core testing of the finished concrete.

(A.G. Eason)
Building Authority

Ref. : BLD(B) GP/BREG/C/7

First issued December 1982
This revision August 1990 (GSE)

Index under : PFA
Pulverised Fuel Ash

Buildings Ordinance Office Practice Note 90

per year in import expenditure for cement and clinker.

The producers and users of structural concrete in Hong Kong will also benefit considerably. This is because:

- PFA is readily available;
- PFA is less expensive than cement;
- PFA produces a better quality concrete.

To address technical questions concerning the use in Hong Kong of PFA as a partial cement replacement in the manufacture of structural concrete, China Light & Power earlier initiated an on-going programme of its own using locally available aggregates, cement and sands. The results to date are generally in line with studies made by ash organisations and independent consultants worldwide. More importantly, they reinforce the very positive results actually realised by the endusers of PFA concrete in the UK, USA and Australia for over 40 years.

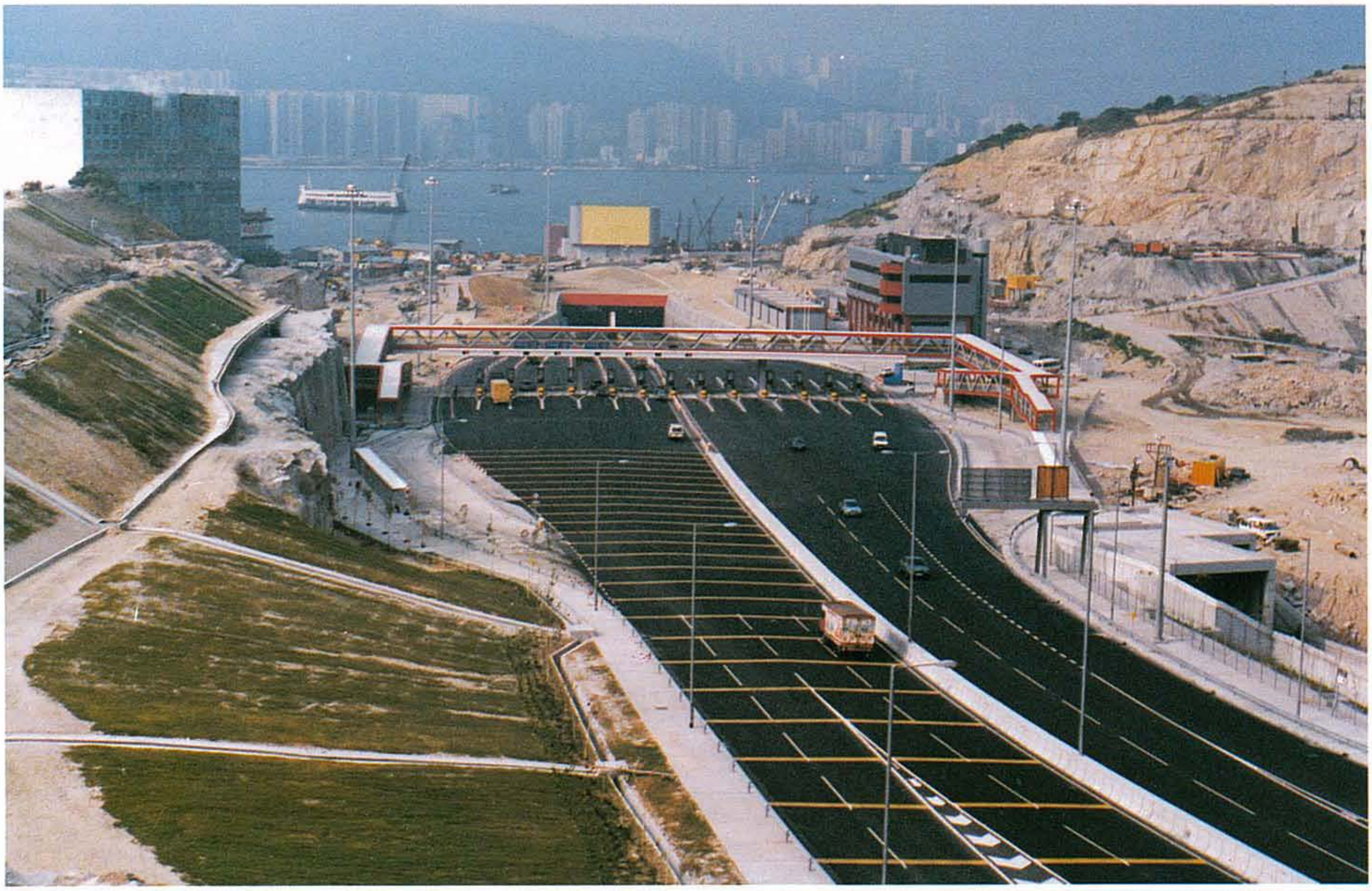
Technical Support

China Light & Power will shortly be publishing its *PFA Concrete Studies*, a comprehensive 9-volume series that reports extensively on the use of PFA in the Hong Kong context. Other literature on the varied applications of PFA in the Hong Kong construction industry is available.

To assist Hong Kong's producers and endusers of structural concrete wishing to use PFA in their mixes China Light & Power established an Ash Marketing Branch in 1988, and operates its own Ash Materials Laboratory.

PFA Concrete and Reclamation Fill for the Eastern Harbour Crossing

煤灰在東區海底隧道的應用



Introduction

The Eastern Harbour Crossing (EHC), which opened in 1989, forms the second vital road and rail link between Hong Kong Island and the mainland. Large quantities of Pulverized Fuel Ash (PFA) were used as a cementitious material in the concrete tunnel units and structures and as a lightweight marine fill over the immersed tube tunnel units.

The Project

Costing $3.4 billion, the EHC is the largest single transportation project undertaken by the private sector in Hong Kong. Government granted the franchise to design, finance, build and operate the crossing under the Eastern Harbour Crossing Ordinance, allowing the project to commence on the 6th August 1986.

The project involves construction of an immersed tube tunnel to carry dual-lane highway and Mass Transit Railway links between Hong Kong Island at Quarry Bay and Kwun Tong in Kowloon. The tunnel is almost 2.3 km between portals, 1.86 km being constructed using the immersed tube tunnel technique and the remainder in cut and cover. The immersed tube tunnel comprises 15 units, each weighing more than 40,000 tonnes and laid in a trench excavated in the sea bed.

PFA was used both in concrete and as a marine reclamation fill for this project for technical and economic reasons.

PFA in Concrete

Virtually all of the 350,000m^3 of concrete used on this project

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例

Mix Grade	D30/20
Cementitious Content (kg/m^3)	380
PFA (as % OPC + PFA)	25
Water/Cement Ratio	0.45
Aggregate/Cement Ratio	4.65
Admixture (1/m^3)	1.11
Slump (typical) (mm)	90
Compressive Strength (MPa)	
7-day	33
28-day	50
28-Day Standard Deviation (MPa)	4.5

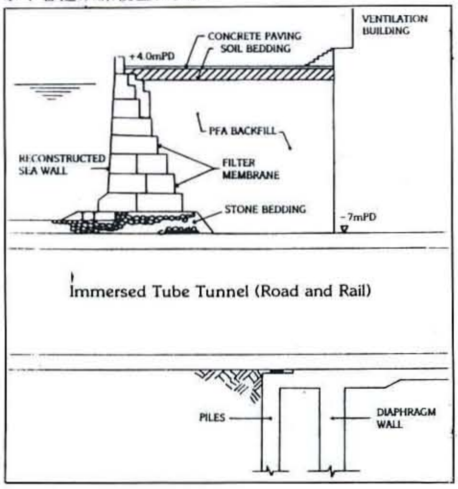
incorporated PFA as up to 25% of the cementitious component.

The PFA was supplied both in the form of a composite OPC/PFA cement and also as a separate material for site batching.

The immersed tube units, which measure 35.5m wide by 9.75m deep and between 122 and 128m in length, require massive sections of reinforced concrete. Early studies indicated that the most effective concrete mix for strength and durability and to minimise thermal cracking and shrinkage in these massive sections would be a 30/20 grade mix containing PFA as 25% of the cementitious component. Some 250,000m^3 of this mix was supplied.

About 100,000 m^3 of PFA concrete was placed in the landbased structures by pump and skip. The concrete for these applications included 30-45/20 grade mixes which were used in construction of tunnel linings, and roads.

Section showing PFA reclamation fill placed over immersed tube tunnel units.
水下管道以煤覆蓋剖面圖



前言

一九八九年通車的東區海底隧道，是接駁香港島與九龍另一重要通道工程中使用了大量煤灰作爲煤灰混凝土及海底管道上之輕質填土。

工程內容

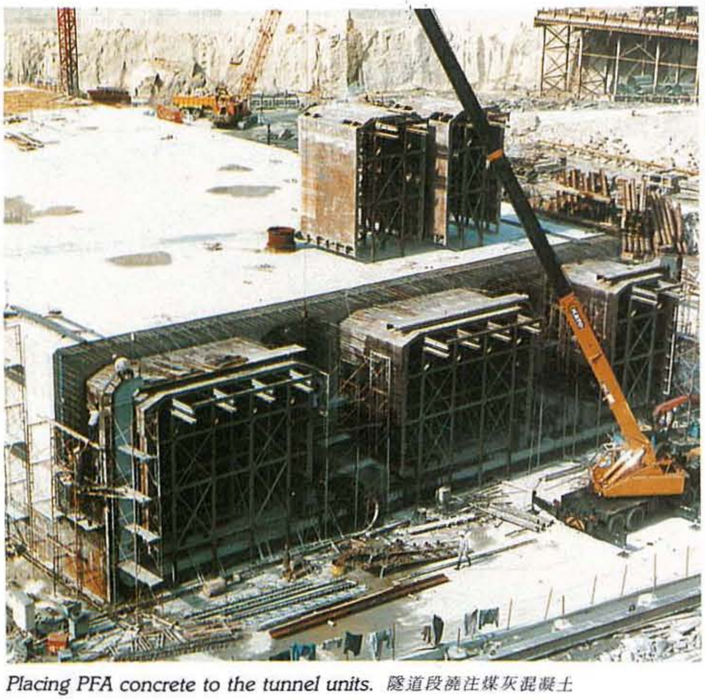
隧道工程耗資34億港元，是本港私人建造商歷來承造最大的單項運輸工程。港府根據東區海隧條例，將隧道設計、集資、建造及經營權全部批給私人發展商，並於1986年8月6日動工。

工程內容是建築汽車通道及地鐵雙線海底隧道，連接港島鰂魚涌及九龍觀塘，兩端全長約 2.3公里 ，用沉管技術建築1.86公里，其他路段則用路面挖開修築接駁。隧道預製沉管共15段，各重四萬多噸，埋設在海床的溝內。

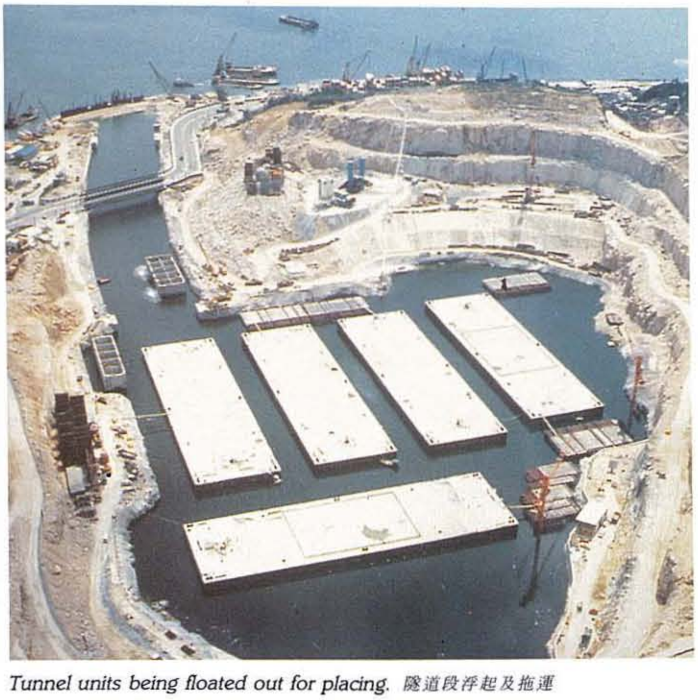
基於技術和經濟理由，隧道工程採用煤灰作爲混凝土料及塡海土料。

煤灰混凝土

隧道工程所用35萬立方混凝土，幾乎全部都有煤灰；而煤灰含量達水泥成份四分之一以上。



Placing PFA concrete to the tunnel units. *隧道段澆注煤灰混凝土*



Tunnel units being floated out for placing. *隧道段浮起及拖運*

The PFA concrete performed as predicted and the added workability and reduced thermal problems with the PFA mix were a distinct advantage, particularly in the large pours of 800m^3 and more to the tunnel units. Both the strength and workability were consistent to a degree not always achieveable with OPC alone.

The use of PFA concrete also permitted significant savings in the materials cost of the concrete, compared to the equivalent OPC mixes.

PFA as Marine Fill

Around 15,000 tonnes of PFA was also used as a lightweight marine fill to reinstate the seafrontage over the immersed tube units at each end of the harbour crossing. PFA fill was chosen in preference to other, heavier fill, in order to minimise the differential loading on tunnel units 1 and 15 where they pass under the sea walls and reclamation to connect with the land-based tunnels.

Placing the PFA

PFA was supplied from the Castle Peak Power Stations in conditioned form (moistened with fresh water) and was transported to site in open barges. The material was placed by grab behind the reconstructed sea walls, in up to 9m of tidal water. A geotextile fabric (Typar 3857) was placed on the landward side of the concrete block sea walls in order to retain the PFA and act as a filter. Up to 1000 tonnes of conditioned PFA were supplied daily to site in 1500-tonne capacity barges loaded directly at the power stations.

PFA placed below water, levelled itself quickly over the whole reclamation area. This material was not compacted but, once a level of +2mPD had been reached, was immediately able to support tracked plant. The PFA was then spread and lightly compacted by loaders and excavators before placing a permanent cover of soft fill and concrete pavement.

Insitu Properties

Filling of the Quarry Bay site was completed in October, 1988. Insitu boreholes revealed that the PFA

煤灰混凝土的混合方法有兩種，在水泥制造過程中直接加進煤灰成混合水泥或地盤現場拌合材料。

海底隧道管道每段長122至128米不等，寬35.5米，深9.75米，由巨型鋼筋混凝土件併成。初期研究指出，配拌強度及耐久性兼優的混凝土料，及減少巨型混凝土件熱裂、收縮，採用30/20級配比拌料，其中煤灰佔水泥成份四分一有較佳效果。這種拌料供應了二十五萬立方米。

地面結構，需要泵送倒卸煤灰混凝土約十萬立方米，其中也採用了30－45/20級配比拌料，修築隧道兩壁及車道。

煤灰混凝土築後性能，悉如預計。配拌煤灰還帶來拌和性提高、熱裂問題減少等好處；尤其是800立方米以上隧道大段的澆築，優點格外明顯，強度及拌和性兼優；純普通水泥混凝土却無此等優點。

混凝土料價亦因採用煤灰，而較同等普通水泥拌料節省不少成本。

煤灰作海底填料

港九兩端隧道口也採用了約1.5萬噸煤灰料修築沉箱上的海灘，寧取煤灰而捨棄較重的其他填料，是要減少第1及15兩段位於防水海堤及塡海地段下，與連接地面段荷載差距的問題。

澆注煤灰

青山發電廠提供煤灰濕料（用淡水濕

Placing geotextile filter membrane.
舖設濾膜布層

Loading conditioned PFA into barges.
煤灰濕料裝（駁）船

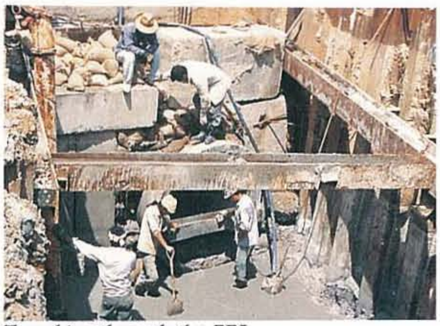
Placing PFA in reclamation.
煤灰塡海

Monitoring instruments.
監測儀表

Placing PFA above water level.
在水面上澆注煤灰

Handling the PFA. *煤灰的處理*

Sample of fill placed below and above water.
於水下、水上的塡料樣本



Trenching through the PFA.
煤灰層掘溝

Completed reclamation, Quarry Bay.
鰂魚涌塡地竣工

placed in water had rapidly consolidated to densities in the range 1.0 to 1.3 Mg/m^3, corresponding to 70 to 95% of Proctor Maximum Dry Density, with an average insitu moisture content of 37%.

PFA fill was also used above tunnel Unit 15 at Cha Kwo Ling in order to limit settlement. The opportunity was taken to install geotechnical instrumentation to monitor the dynamic properties of the PFA fill during placement. This confirmed that the PFA consolidated rapidly on placing and little further settlement occurred during subsequent filling. Insitu boreholes also confirmed similar densities in the PFA fill to those achieved at the Quarry Bay site.

After backfilling, trenching to a level of − 3mPD in the PFA reclamation was carried out for construction of large diameter stormwater drains. Normal sheet piling and excavation methods were employed and no special difficulties were encountered in trenching and pipe laying, despite the inflow of water through the sea wall.

Conclusion

PFA has proven itself a successful and versatile construction material in many vital components of the Eastern Harbour Crossing Project. Its special properties in concrete and fill have provided a significant contribution to the timely completion of this major project.

Acknowledgements:

Client:
New Hong Kong Tunnel Co Ltd
Designers:
Freeman Fox and Partners, Far East
Oakervee Perrett (Asia) Ltd
Principal Contractor:
Kumagai Gumi Co Ltd
Project Manager:
EHC Project Management Co Ltd
Geotechnical Consultant to China Light & Power Co Ltd:
Binnie Consultants Ltd
Concrete Suppliers:
Ready Mixed Concrete (HK) Ltd
Pioneer Concrete (Hong Kong) Ltd

潤），由駁船送至地盤，再由抓斗卸在海堤內，堆填高達9米水深。海堤舖上一層Typar 3857布膜以防阻煤灰流失。1,500噸級駁船每日從電廠，裝運上千噸煤灰濕料，送至地盤。

在水底舖放，煤灰會自行攤平，迅速舖滿整片填地；到了標高上兩米處，不必壓實也可支撐鏈帶機械。再由搬運機及挖土機攤開，稍加壓實，最後蓋上一層軟填料和混凝土舖面。

在施工現場特性

鰂魚涌段填海工程，於1988年10月竣工，地盤鑽探證實，水下澆注煤灰料迅速固結，密度由1.0至1.3兆克/立方米，相當於70－95%普氏最大乾密度，其含水量平均37%。

茶果嶺15號海隧管道，也採用煤灰填料，限制沉降程度，同時亦埋設土力測量儀表，監測煤灰填料舖放過程的動態，監測結果證實，煤灰迅速固結，隨後填舖時，亦甚少再下沉。鑽探提取樣本也證實，茶果嶺及鰂魚涌兩段煤灰填層，密度相近。

煤灰料回填築地，然後開溝，深逾標高下三米，舖設大口徑雨水道。採用常用板樁，掘土等法開溝舖管，海堤雖有水滲入，但施工時未遇特別困難。

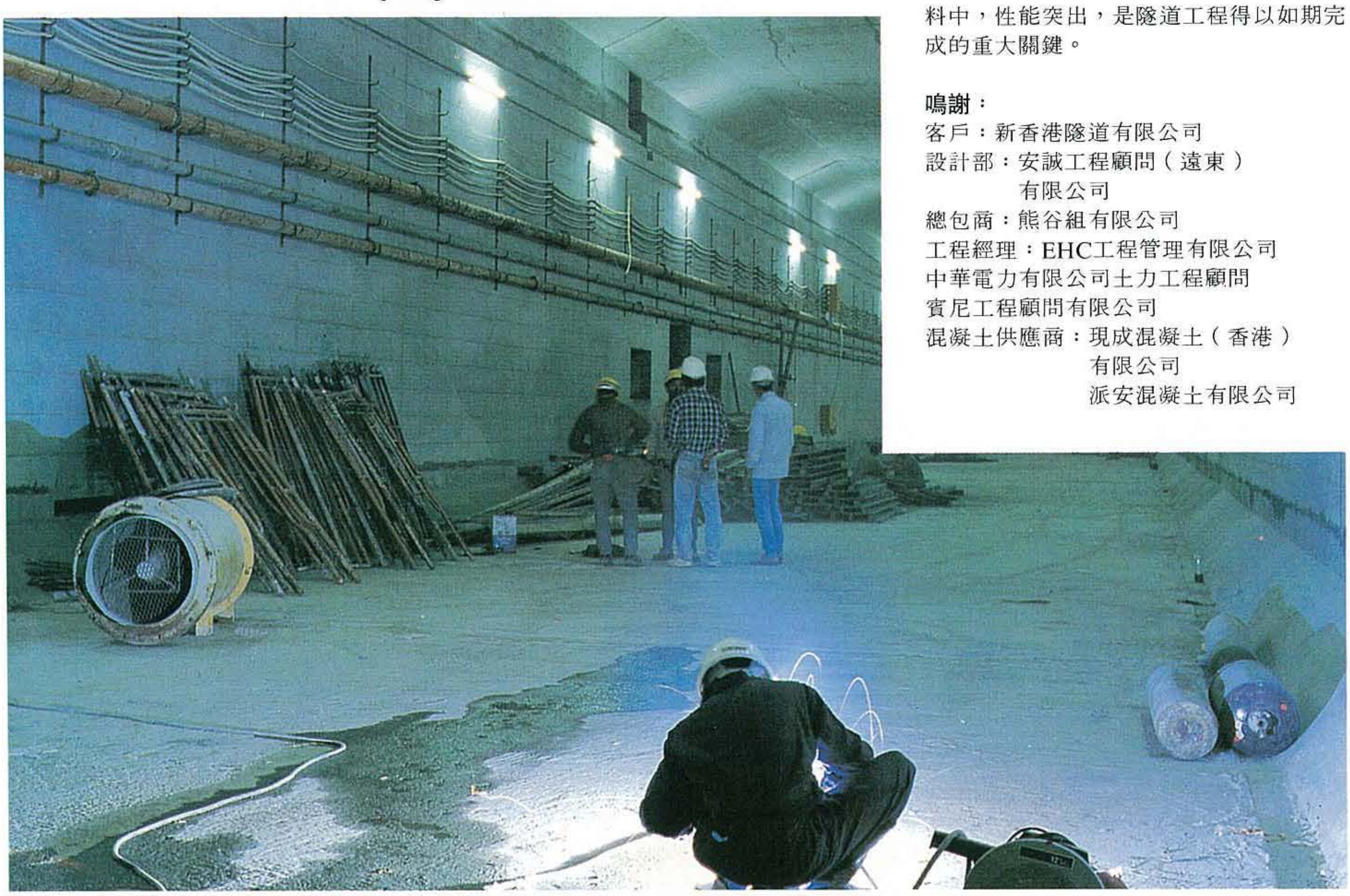
結論

煤灰用於東區隧道工程多項要件，成效斐然，確爲建築良材。它在混凝土及填料中，性能突出，是隧道工程得以如期完成的重大關鍵。

鳴謝：

客戶：新香港隧道有限公司
設計部：安誠工程顧問（遠東）有限公司
總包商：熊谷組有限公司
工程經理：EHC工程管理有限公司
中華電力有限公司土力工程顧問
賓尼工程顧問有限公司
混凝土供應商：現成混凝土（香港）有限公司
派安混凝土有限公司

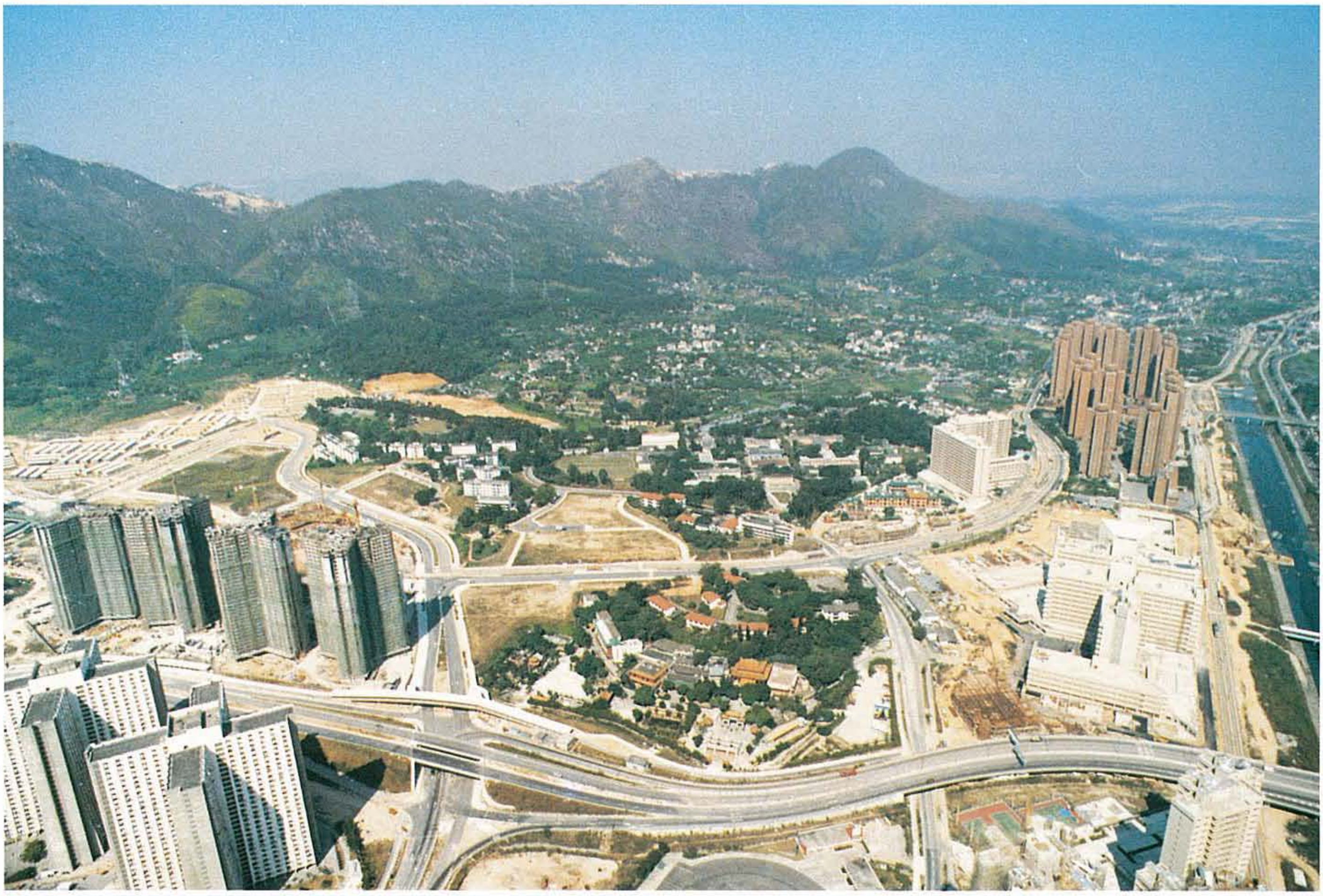
Interior of immersed tube tunnel unit after placing. 安放好隧道管道的內景

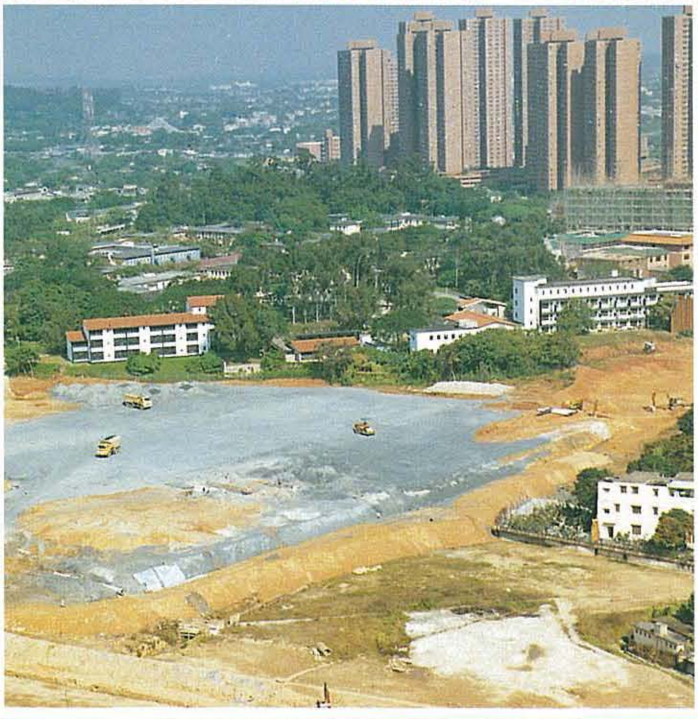


China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*
147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

PFA Fill for Tuen Mun New Town Infrastructure

煤灰填料用於屯門新市鎮





Introduction

Site formation for more than 10 hectares of Tuen Mun New Town has utilised Pulverized Fuel Ash (PFA) as load-bearing fill above high tide level.

The PFA was supplied from the Castle Peak Power Stations and was placed as part of 3 contracts for site and infrastructure formation between 1984 and 1987.

The filled areas now support several of the new town developments, including high-rise structures, road embankments and part of the Light Rail Transit (LRT) system.

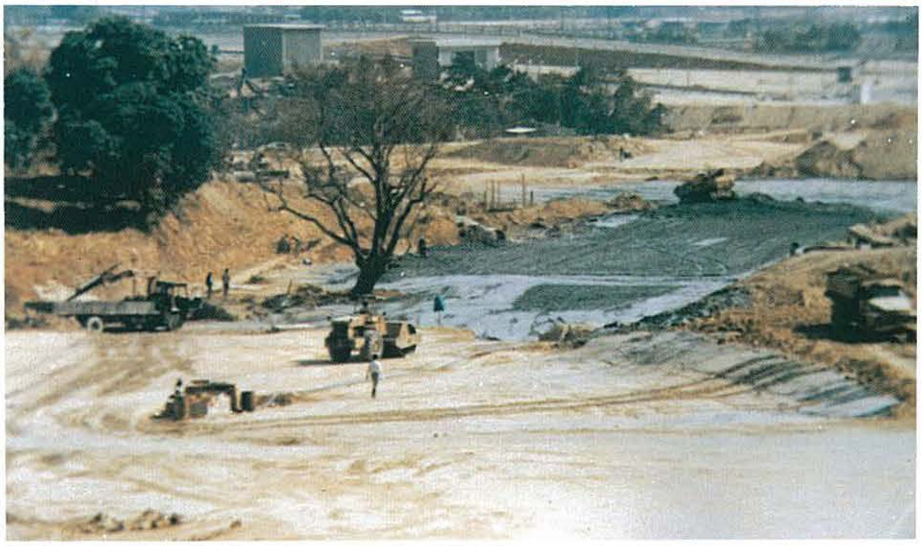
The Projects

A total of more than 160,000m^3 of PFA was placed in depths of up to 6m to form the sites for construction of public housing estates, a school, police and fire stations, access roads, LRT tracks and highway interchange embankments.

Placing the PFA

Conditioned PFA (PFA moistened with fresh water) was delivered from the Castle Peak Power Stations in 15-tonne capacity end-tipping trucks fitted with tarpaulin covers to prevent drying or spillage of the PFA in transit.

At site, the PFA was placed and compacted, in layers of up to 500mm thickness, to not less than 95% Standard Proctor Maximum Dry Density. Compaction was typically achieved by 6 to 10 passes of a 10-tonne vibrating roller, yielding insitu dry densities generally in the range 1.1 to 1.3 Mg/m^3. The average daily quantity of PFA placed varied from 300 to 900m^3.



Placing PFA to Area 2A, Tuen Mun. 屯門2A區鋪填粉煤灰

前言

屯門新市鎮十多公頃以上的土地平整工程中，大都採用煤灰作爲承重填料。煤灰由青山發電廠供應，是一九八四至一九八七年間三項工地平整和基建設施合約所用物料的一部份。新填地上高樓大厦矗立，亦興建了路堤和輕鐵屯門段等。

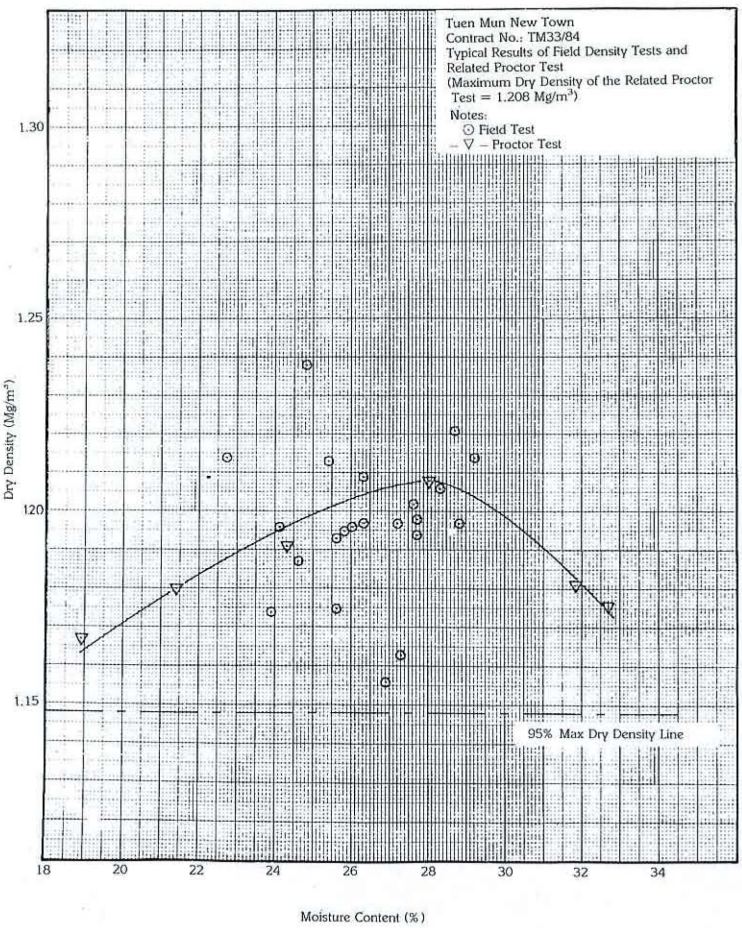
填地工程

超過160,000㎥煤灰應用在填地工程，厚度有高達6米，上築有公共屋邨、學

Contract TM 29/84. TM 29／84號合約

Contract 998190/84. 998190／84號合約

Typical compaction results for PFA fill. 煤灰填料壓實測驗典型成果



校、警署、消防局、通道、輕鐵路軌以及公路、天橋、路堤。

澆注煤灰

青山發電廠煤灰濕料（淡水調濕的煤灰料），載量15噸的尾卸車裝運，上覆油布，以防途中煤灰晾乾或傾瀉。

在地盤舖上煤灰，每層500毫米厚，普氏標準最大乾度不少於95%。使用十噸重振盪壓路機在上壓六至十次，通常便可壓實。現場澆注乾密度一般介乎1.1至1.3兆克/立方米。每日澆注煤灰量平均300－900立方米。

顧及環境

地盤北連青山醫院，南面是大興邨，東邊是農村及寺院，儘管有大面積填上煤灰，但也採取足夠措施，所以沒有對附近環境造成影響。

用人工灑水防止煤灰飛散，成效圓滿，並保證煤灰填層濕度合宜，便於碾壓。每日收工時再次灑水，確保夜間煤灰不致飛散。煤灰填地完工後，在上面蓋有300毫米厚的表土。

煤灰運載及碾壓方法，行之有效。在一些對環境特別敏感的住宅區放置煤灰並沒有出現塵土飛揚的問題。

Environmental Considerations

The site was bordered by the Castle Peak Hospital to the north, the Tai Hing public housing estate to the south and a village area and monastery to the east. Care was thus taken to eliminate nuisance to residents, despite the large areas of PFA fill being placed.

Satisfactory control over fugitive dust was achieved by manual water spraying, which also ensured that the PFA fill was close to optimum moisture content for compaction. At the end of each day, any remaining piles of PFA delivered during the day were spread, compacted and sprayed with water to ensure no dust blow occurred overnight. On completion, a 300mm thick permanent cover of soil was placed over the PFA.

The handling and compaction methods employed proved effective and no practical problems were encountered with the control of dust in this sensitive residential area.

Indeed, according to the Chief Resident Engineer, PFA which had dried, after spreading and compaction, produced little dust even on days when the wind was raising clouds of dust from soil fill on other parts of the site. PFA filling, if properly controlled, can be expected not to give rise to dust problems in the short term even when the PFA is allowed to dry out provided it has been properly compacted.

Piling, trenching and handling the PFA fill presented no difficulties at Tuen Mun.
煤灰填料不會在打樁，開溝及處理上引起不便

Contract TM 33/84 used PFA fill for highway embankments. The buildings behind are built over PFA fill. TM 33／84號合約煤灰塡築公路路堤。堤後建築物均建於煤灰塡地上。

據地盤工程師說，就算在刮風天，風對地盤其他地方掀起陣陣微塵，但在用煤灰塡壓的地方却無塵土飛逸現象。妥善碾實的煤灰塡料土上，即使塡料正在乾燥中，亦不致惹起灰塵問題。

煤灰的優點

煤灰證實較普通塡料便宜百分之四十。使用煤灰更可避免因租地而引起了環境污染問題，雨季停工時間更大爲減少。

煤灰容易處理和輾壓，塡地堅固均勻，適用於道路、結構物和鐵路的基礎工程。

鳴謝：

客戶：香港政府新界拓展署工程經理（屯門）及青山發電有限公司

顧問工程師：史偉高顧問工程師

承建商：堅正百歲有限公司
（998190/84號合約）
飛島建設株式會社
（TM29/84號合約）
公和建築有限公司
（TM33/84號合約）
中國建築海外有限公司
（TM36/84號合約）

Why PFA?

PFA proved to be an economical alternative to conventional fill, as the average contract rates for placing PFA were some 40% lower than those for soil. The use of PFA also avoided the impact on the natural environment associated with land-based borrow areas and significantly reduced downtime due to wet weather.

PFA is easy to handle and compact and produces a robust and uniform lightweight fill suitable for foundations of structures, roads and railways.

Over 2 million tonnes of PFA from Castle Peak have been used as fill to date in site formation, marine and marsh reclamation in Hong Kong, Macau and China.

LRT tracks constructed on PFA fill. 在煤灰塡料地上鋪建的輕鐵軌道。

Acknowledgements

Clients:
Project Manager (Tuen Mun), Territory Development Department, Hong Kong Government, and Castle Peak Power Company Limited

Consulting Engineer:
Scott Wilson Kirkpatrick & Partners

Contractors:
Kin Ching Besser Co Ltd
(Contract 998190/84)
Tobishima Corporation
(Contract TM 29/84)
John Lok & Partners
(Contract TM 33/84)
China State Construction Engineering Corporation
(Contract TM 36/84)

China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*
147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

PFA Fill for Tuen Mun Roads and Interchange
屯門道路及天橋工程使用煤灰

Introduction

This contract for the construction of major roads and an interchange was carried out as part of the development of Tuen Mun New Town. The contract specification permitted filling material for road embankments to be either Pulverized Fuel Ash (PFA) from the Castle Peak Power Stations or conventional soft fill. After thorough evaluation, PFA was chosen for economic and technical reasons.

The Project

A flyover with approach embankments was required as part of the highway interchange constructed under Contract TM 33/84.

The embankments, which used a total of 18,500m^3 of PFA, were up to 6m high with side slopes of 1 in 1.7 and varied in width from 23 to 40m. The PFA works commenced in February 1986 and were completed in late 1987.

前言

屯門新市鎮拓展規劃中，包括建築主要道路及天橋。合約容許路堤填料可用青山發電廠煤灰或普通填料。通過週詳考慮，基於經濟及技術理由，決定選用煤灰。

工程項目

TM33/84號公路及天橋建築合約：

路堤共用二萬八千立方米煤灰，最高達6米，坡度1/1.7，寬度不一，由23至40米。1986年2月動工，1987年底完成。

Placing of PFA

Conditioned PFA (PFA moistened with fresh water) from the Castle Peak Power Stations was transported 8km to the site in 15-tonne capacity end-tipping trucks fitted with tarpaulin covers to prevent the PFA from drying or spilling. The average daily quantity of PFA delivered was 600 tonnes.

The PFA was spread by crawler loaders and compacted in 500mm layers using 6 to 10 passes of a 10-tonne vibrating roller. Site tests confirmed that compaction of the PFA achieved the specified requirement of 95% of the Maximum Dry Density, yielding in-situ dry densities generally in the range 1.15 to 1.27 Mg/m^3.

The moisture content of the PFA was controlled by manual water spraying, in order to ensure the material was close to optimum moisture content for compaction and to prevent fugitive dust. On completion of filling, the PFA was covered with a 300mm thick layer of soil, which was hydroseeded.

The handling and compaction methods employed proved effective and no practical problems were encountered with the control of dust in this sensitive residential area.

Spreading and placing PFA. 煤灰鋪整情況

Why PFA?

Due to its light weight and inert characteristics, PFA is highly suitable for construction of road embankments, as it imposes low lateral loading on abutments and retaining walls and minimises differential settlement. PFA is generally less compressible than other fill materials used in Hong Kong and, due to its light weight, the loading on weak ground is reduced compared to conventional fills. It is easy to compact and produces a robust and uniform fill suitable for foundations of roads and structures.

The use of PFA on this project avoided the impact on the natural environment associated with using land-based borrow areas. Downtime following wet weather was also significantly reduced, as PFA fill drains relatively quickly, so that site work can recommence soon after rainfall.

The contract rates for placing and compaction of PFA were similar to or slightly greater than those for soil fill.

Over 2 million tonnes of PFA from the Castle Peak Power Stations have been used as fill to date in site formation, marine and marsh reclamation in Hong Kong, Macau and China.

Acknowledgements

Client:
Project Manager (Tuen Mun)
Territory Development
Department, Hong Kong
Government

Consulting Engineer:
Scott Wilson Kirkpatrick & Partners

Contractor:
John Lok & Partners
(Contract TM 33/84)

澆注煤灰

青山發電廠煤灰濕料（淡水調濕的煤灰），由載重15噸尾卸車裝運，送至8公里外地盤，上蓋油布，以防煤灰晾乾或傾瀉。平均每日運送600噸煤灰。

煤灰由履帶裝機攤開，再用十噸輥式震搗機輾/壓，每層500毫米厚，來回輾壓6－10次。地盤測試證實，煤灰壓實度達到規定要求，爲最大乾密度的95%，現場乾密度一般介於1.15至1.27兆克/米³。

用人工灑水，控制煤灰的含水量，確保含有最佳濕度，適於輾壓，而又防止飛塵，填築完成時，在煤灰上，鋪蓋一層300毫米厚的表土，然後用薄膜水養法播種及鋪草。

裝載碾壓方法，行之有效，在控制灰塵方面並無問題，不致對住宅區環境造成影响。

煤灰優點

煤灰質輕性惰，尤宜建築路堤；它使橋躉及擋土牆承受側向負荷較少，又可將差異沉降現象減至最低。在抗壓性方面，煤灰一般高於本港所用其他填料。由於其輕便特性，在軟地上之負荷較普通填料爲輕，又易輾壓，填地堅固均勻，適用於道路及結構物基礎工程。

路堤工程使用煤灰，免除環境污染問題；亦不怕潮濕。雨季停工時間大爲減少，且因煤灰填地排水較速，落雨後不久即可開工。

本項合約中，煤灰的供應，鋪填及輾壓的費用，比用同量泥土填料工程低30%以上。

青山電廠迄今已向香港、澳門及中國供應二百多萬噸煤灰，作爲平整地盆、填海和沼澤的材料。

鳴謝：

客戶：香港政府新界拓展署工程經理
（屯門）
顧問工程師：史偉高顧問工程師
承建商：公和建築有限公司
（TM33/84號合約）

Placing PFA fill in the embankments. 澆築橋台煤灰填層

The completed embankment after grassing. 路堤竣工鋪草後全景

China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*
147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

Foreshore Reclamation at Tuen Mun Using PFA
屯門海灘煤灰堰築工程

Introduction

Pulverized Fuel Ash (PFA) was used as an alternative to conventional soft fill to reclaim a sea front area of about two hectares at Area 47S Pillar Point, Tuen Mun. The site was a former river bed and foreshore area and the reclaimed area was handed back to Government for industrial development.

The Project

The project involved construction of a 120m long temporary rubble-mound sea wall along the southern boundary incorporating a geotextile filter to contain the PFA. The site was levelled to around 0mPD and was filled with an average depth of about 4m of PFA to final levels. The total volume of PFA placed was 50,000m^3. This project commenced in February 1988 and was completed in July 1988.

Placing of PFA

Conditioned PFA was collected from the Castle Peak Power Stations and transported 3km in 15-tonne capacity end-tipping trucks fitted with tarpaulin covers to prevent drying and spillage of the PFA. At site, the PFA was spread by loader and compacted in layers using vibratory rollers to achieve a minimum compaction of 95% Maximum Dry Density. Test results showed that compaction of the PFA was satisfactory. The average daily quantity of PFA placed ranged from 300 to 1000 tonnes. No difficulties were experienced in placing the PFA in the tidal zone behind the seawall.

前言

屯門47S區約2公頃海灘的填海工程中，採用煤灰來代替常用軟料。該地盤原先爲河床及瀕海灘地，經填實後，交還政府作工業發展之用。

工程內容

本項工程是在南線築一道120米長的臨時時堆石防浪海堤，當時曾鋪築地纖濾層，以阻止煤灰流失。地盤平整至標高0米，而煤灰塡層平均約深4米，一直鋪到頂層，煤灰用量總計5萬立方米。此項工程於1988年2月動工，同年七月竣工。

煤灰的填佈

青山發電廠煤灰濕料，由載量15噸之尾卸車裝運，上蓋油布，以防煤灰吹乾或外溅。運至地盤後，分層由裝載機攤開，再由震動壓路機輾壓，壓實度最低達到最乾密度的95%。測試結果證明，煤灰壓實度良好，平均每日塡佈300－1000噸煤灰。海堤後面的進潮區，塡佈煤灰時並無困難。

Environmental Considerations

As the site was adjacent to a sewage treatment plant to the west and Lung Mun Road immediately to the north, care was taken to ensure that no nuisance was caused to the public. Dust control was achieved by manual water spraying, which also ensured that the material was close to optimum moisture content for compaction. The handling and compaction methods employed proved effective and few practical problems were encountered with the control of dust. A wheel washing bay prevented fill from being carried onto the adjacent public road.

On completion, a 300mm thick permanent cover layer of soil was placed over the PFA for landscaping purposes, pending development of the site for industrial usage.

PFA delivery by truck. 貨車運送煤灰粉

Why PFA?

PFA proved to be a suitable alternative to conventional fill for marine reclamation. It avoided the impact on the natural environment associated with using land-based borrow areas and significantly reduced downtime due to wet weather.

PFA is easy to handle and compact and produces uniform lightweight fill suitable for foundations of roads, railways and structures.

Over 2 million tonnes of PFA from the Castle Peak Power Stations have been used as fill to date in site formation, marine and marsh reclamation in Hong Kong, Macau and China.

Acknowledgements

Client:
Castle Peak Power Company Limited

Consulting Engineer:
Scott Wilson Kirkpatrick & Partners

Contractor:
Kin Ching Besser Co Ltd

環境影響

由於地盤西面是污水處理廠，北面與龍門路接壤，因而採取措施，確保公衆環境不受影響。用人工灑水防止灰塵飛揚，又可保證填料含水量適宜，便於輾壓。實踐證明，所用的運送及碾壓方法確實有效，防止了灰塵飛揚。另特設車輪冲洗設施以防車輪將煤灰帶到鄰近公路去。工程完成後，在煤灰上舖蓋300毫米厚的表土，使環境美化，待日後將土地作工業發展用。

煤灰優點

煤灰可以代替普通填料，作爲填海用途，可不必在其他地方挖掘填料，從而避免環境污染，及大大減少因天氣潮濕而停工之日數。

煤灰易於裝載碾壓，具有均勻輕質特點，適宜用於道路、鐵路及結構地基工程。

青山發電廠迄今已供應超過二百萬公噸煤灰，用於香港、澳門及中國的工地平整、填海及填沼澤地工程。

鳴謝：

客戶：青山發電有限公司

顧問工程師：史偉高顧問工程師

承造商：堅正百歲有限公司

PFA filling operations in progress. 煤灰粉填築施工景象

Moisture content adjustment. 含水量調整

General view of Area 47S showing compaction trials in progress. 47S 區全景

China Light & Power Co., Ltd.

中華電力有限公司 *Ash Marketing*

147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

PFA Concrete Construction at Route 5

五號幹綫煤灰混凝土工程

Introduction

Completed in 1990, Route 5 links the growing new towns of Sha Tin and Tsuen Wan. This project has used nearly 200,000m^3 of concrete containing Pulverized Fuel Ash (PFA) for the construction of tunnel linings, road pavements, walkways, highway and building structures.

The Project

The $1.2 billion project is a 7km long dual-lane trunk road forming part of the New Territories Circular Route. It is divided into three sections: Sha Tin Connection, Shing Mun Section and Tsuen Wan Connection.

Costing over $700 million, the Shing Mun Section includes twin two-lane tunnels under Smugglers Ridge and Needle Hill, linked by a pair of bridges over the lower Shing Mun River Gorge. The Smugglers Ridge tunnels are 1 km long, whilst the Needle Hill tunnels are 1.6 km long.

The Sha Tin Connection, valued at $210 million, includes a 2.2 km dual two-lane carriageway, 1.2 km of which is elevated, and three flyovers.

The Tsuen Wan Connection, valued at over $160 million, involves the construction of major road interchanges, foot bridges and subways. Improvements are also being made to existing roads to upgrade them to trunk road standards.

PFA concrete was used in the Shing Mun tunnel linings. 城門隧道襯牆採用煤灰混凝土

The civil contractor for the Shing Mun Section is the Gammon – Dragages – Skanska Joint Venture, comprising Gammon Construction Ltd, Dragages et Travaux Publics, and Skanska AB. The contractor for the Sha Tin Connection is Shui On Civil Contractors Ltd, whilst that for the Tsuen Wan Connection is Aoki Corporation.

Why PFA ?

Following thorough evaluations,

Placing PFA concrete to road pavements
用PFA 混凝土鋪路面。

前言

五號幹綫已於1990年完成，連接沙田及荃灣。工程使用了煤灰混凝土近20萬立方米，以建造隧道襯牆、路面、行人道、公路及結構工程。

工程內容

五號雙綫幹道長7公里，耗資12億港元，爲新界環廻公路組成部份，分爲沙田、城門、荃灣三段。

城門段需費超過7億元，在孖指嶺及針山脚建造雙管雙線行車隧道，並於下城門河谷建兩條橋架，將兩隧道聯成一線，其長度分別爲1公里及1.6公里。

沙田聯線需2.1億元爲雙程雙線行車道長約2.2公里，由1.2公里高架道段及三座天橋組成。

荃灣聯線工程造價超過1.6億，建造各主要道路的交接點、行人天橋及隧道，並將舊路翻新成爲標準幹道。

城門段承建商爲Gammon-Dragages-Skanska組合，成員爲金門，法國濬海及瑞典Skanska等公司。沙田段及荃灣兩段分別由瑞安及青木兩家公司承建。

煤灰的功用

經周詳評估後決定，五號幹綫各期工程全部採用煤灰混凝土，理由如下：

- 事實證明煤灰混凝土強度耐久，耐用，並具有耐化學腐蝕的性能。
- 煤灰顆粒渾圓，提高混凝土拌和性及泵送性。
- 煤灰降低水化熱量及減少熱裂。

承建商使用煤灰混凝土可大幅節省成本。

煤灰混凝土

由於煤灰混凝土具有上述特性，故在整項工程的不同應用中用去近二十萬立方米混凝土。

城門段隧道之襯牆及行人道用去九萬

the use of PFA concrete was incorporated in all phases of Route 5 because :

- PFA concrete has a proven record of long-term strength gain, durability and resistance to chemical attack.
- PFA's spherical particle shape improves the workability and pumpability of concrete.
- PFA lowers heat of hydration and reduces thermal cracking.

The use of PFA concrete would also enable significant cost savings to be achieved.

PFA Concrete

As a result of these properties, nearly 200,000m^3 of PFA concrete has been used on the project in many different applications.

On the Shing Mun Section, 90,000m^3 of PFA concrete was used for the tunnel linings and walkways, 9000m^3 for bridge caissons, 2000m^3 for roadworks, and 7000m^3 for the administrative buildings and the approach structures. Most of the concrete for the tunnel linings was pumped, whilst that for the walkways was unloaded from skips into shuttle cars. Concrete for the roadworks was laid by paving gantry and screeded.

The 28,000m^3 of PFA concrete placed at the Sha Tin Connection was used in caissons, pile caps, part of the insitu bridge decks, pavements, walkways and all textured structures.

Over 9000 m^3 of PFA concrete were used for the Shing Mun bridges.
城門橋所用煤灰混凝土超過9000立方米

The bulk of the 58,000m^3 of PFA concrete placed on the Tsuen Wan Connection was used in the construction of an interchange, footbridges, roads and subways.

PFA Supply

PFA originating from Castle Peak Power Stations was used on the Shing Mun Section and Sha Tin Connection. PFA for the Shing Mun Section was supplied by Kin Ching Ash Ltd classified to BS 3892 Part 1 for site batching by Gammon Construction Ltd.

Ken On Concrete Co Ltd supplied the PFA used on the Sha Tin Con-

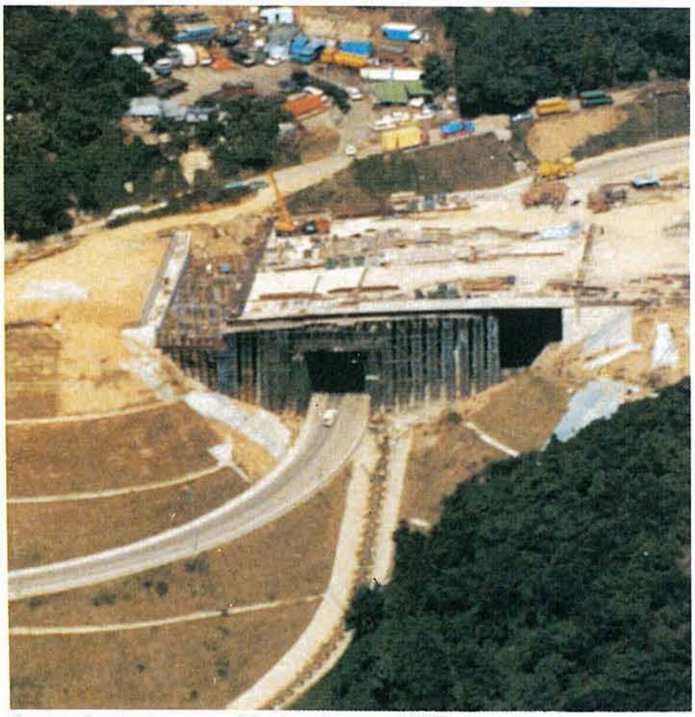
立方米煤灰混凝土，沉箱橋墩則用去9,000立方米，築路用去2,000立方米，而行政大樓用去7,000立方米。隧道襯牆工程多由泵採混凝土泵送，而行人道所用的混凝土用筲斗裝車往返運送。

沙田線沉箱，樁帽，部份橋面，路面，行人道及所有房建構築等項工程中，澆注入煤灰混凝土2.8萬立方米。

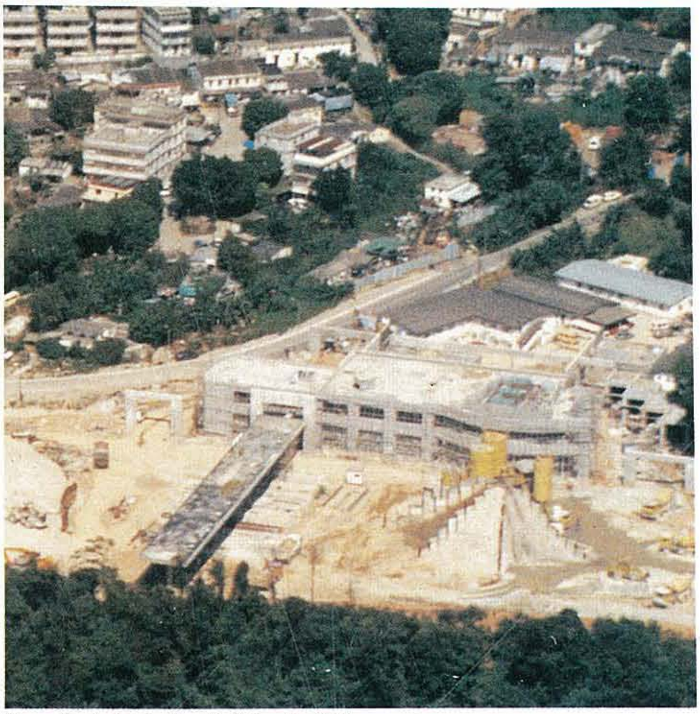
荃灣線澆注煤灰混凝土5.8萬立方米，建造立交橋、行人橋、道路，及隧道等。

供料

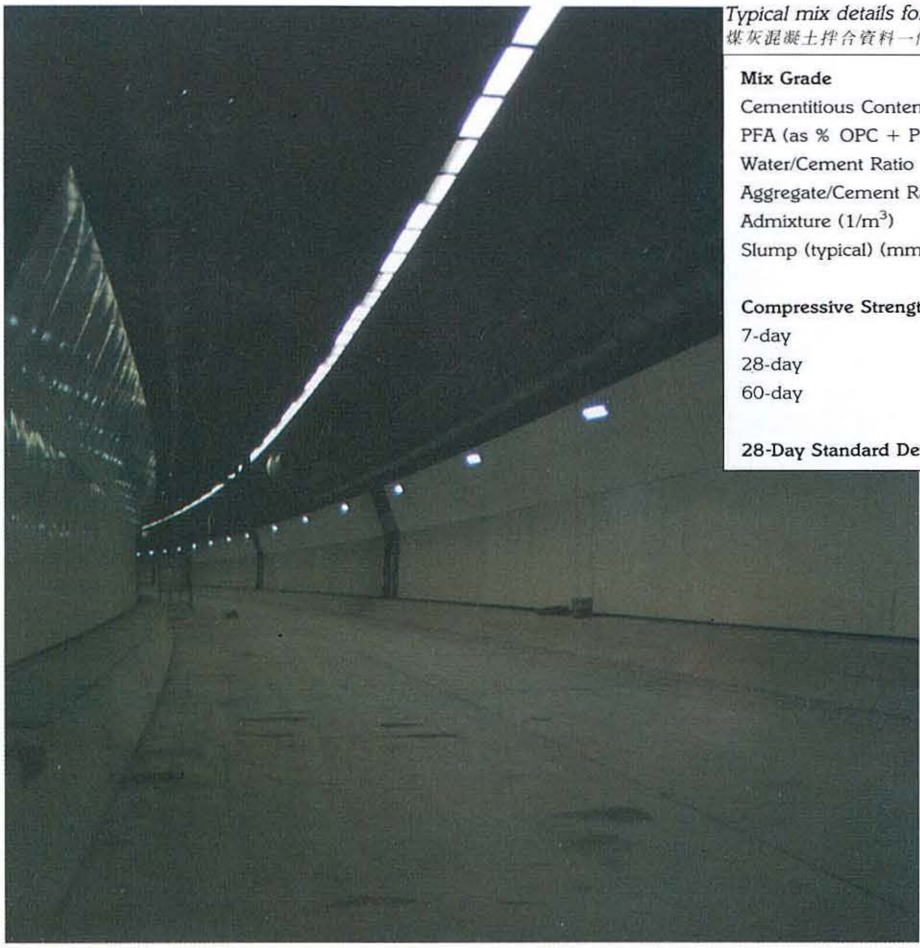
城門段使用青山發電廠的煤灰料，由堅正百歲有限公司供應，質量達到英國標準BS3892號第一部份，再由金門建築有限公司現拌。



Approach structures used large volumes of PFA concrete.
採用大量煤灰混凝土的引道結構



Tunnel administration building in PFA concrete.
採用煤灰混凝土的隧道行政大樓



The completed Shing Mun tunnel. 已完成的城門隧道

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例。

Mix Grade	D30/20	D30/20	D30/20
Cementitious Content	400	370	360
PFA (as % OPC + PFA)	25	27	30
Water/Cement Ratio	0.49	0.53	0.54
Aggregate/Cement Ratio	4.23	4.66	4.82
Admixture (1/m^3)	1	1	1
Slump (typical) (mm)	100	100	100
Compressive Strength (MPa)			
7-day	35	25	22.5
28-day	49.5	38	35
60-day	56	46.5	42.5
28-Day Standard Deviation (MPa)	**4.52**	**3.44**	**4.02**

nection to Shui On Civil Contractors Ltd, sourcing the PFA from China Cement (HK) Ltd.

The PFA used on the Tsuen Wan Connection was sourced from Lamsonite Company Ltd and supplied by Pioneer Concrete (Hong Kong) Ltd to Aoki Corporation.

Typical mix proportions using PFA as 25% of the cementitious component are shown in the accompanying table. These mixes achieved the specified strengths within 28 days, with further strength gains being realised at later stages. This, together with the likelihood of less shrinkage cracking, subsequently resulted in PFA being incorporated as up to 40% of the cementitious component in some elements.

Conclusion

Route 5 is one of a number of important infrastructure projects where PFA has shown itself to be a wise engineering choice for both economic and technical reasons.

Acknowledgements

Clients:
Highways Department and Territory Development Department, Hong Kong Government

Consulting Engineers:
Mott MacDonald Hong Kong Limited (Shing Mun Section)
Maunsell Consultants Asia (Sha Tin Connection)
Scott Wilson Kirkpatrick & Partners (Tsuen Wan Connection)

Contractors:
Gammon – Dragages – Skanska Joint Venture (Contract HY/85/06)
Shui On Civil Contractors Ltd (Contract ST/24/85)
Aoki Corporation (Contract TW41/85)

Concrete Suppliers:
Gammon Construction Ltd
Ken On Concrete Co Ltd
Pioneer Concrete (Hong Kong) Ltd

PFA Suppliers:
China Cement (HK) Ltd
Kin Ching Ash Ltd
Lamsonite Company Ltd

沙田段由中國水泥供煤灰，建安將混凝土混入煤灰後再供應瑞安土建有限公司。

荃灣段煤灰來自Lamsonite香港有限公司，並由派安混凝土香港有限公司供應。

使用煤灰作25%的水泥組合料時，標準拌合比例可參閱附表。這標準拌合可在二十八天內取得特定強度，稍後強度會更佳。由於具有這種強度和減少收縮裂隙，所以有些部份的水泥組合料的煤灰含量更高達40%。

結論

鑒於經濟及技術原因本港重要基礎工程多用煤灰料。五號幹綫只是其中一個例子。

鳴謝：

客戶：香港政府路政署
顧問：Mott MacDonald Hong Kong Limited（城門段）
茂盛工程顧問有限公司（沙田接連）
史偉高顧問工程師（屯門接連）
設計：香港政府工程署（沙田/荃灣段）
承建商：Gammon-Dragages-Skanska組合（合約HY/85/06）
瑞安土木工程有限公司（合約號ST/24/85）
青木有限公司（合約號TW/41/85）
煤灰供應商：金門建築有限公司
建安混凝土有限公司
派安混凝土有限公司
中國水泥（香港）有限公司（煤灰粉料）
堅正百歲有限公司
Lamsonite Company Ltd

China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*
147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

PFA Structural Concrete for Pak Kong Water Treatment Works
北港濾水廠使用煤灰結構混凝土

Introduction

Pulverized Fuel Ash (PFA) has been used extensively as a cementitious component in the concrete used for construction of the Pak Kong Water Treatment Works in Sai Kung. The treatment works occupy a 9-hectare site and, upon completion, will be the second largest of the 17 operated by the Water Supplies Department. Phase 1 of the project, which is the subject of this report, was completed in June 1989.

The Project

The whole project, valued at over $475 million, includes the construction of a water treatment works, pumping station, primary service reservoir, 5.9 km of water tunnels, 1.2 km of pipeline, and associated landscaping work.

Approximately 65,000m^3 of PFA concrete was used in Phase 1 of the project in the structural elements of buildings and in water-retaining structures, including the tanks, aqueducts, culverts, channels and drainage works for the treatment plant structures.

PFA Concrete

Four PFA concrete mixes were used on the site. Most of the structural concrete for buildings and water-retaining structures was specified as Grade 30/20, with a minimum cementitious content (OPC + PFA) of 360 Kg/m^3 and a maximum water/cementitious ratio of 0.5.

The design mixes used contained 385 to 430Kg/m^3 of cementitious material, of which 25% was PFA, and achieved average 28-day strengths in the range of 40 to 46 MPa. PFA was initially batched separately into the concrete but was subsequently included in the form of Portland Pulverized Fuel Ash Cement.

Concrete Placing

All PFA concrete was supplied ready-mixed and was delivered to site in conventional ready-mix trucks. To minimise the possibility of thermal cracking, and to comply with the maximum allowed temperature at placing of 32°C, temperature-controlled concrete was used during the summer months.

Concrete was placed by crane and skip or by concrete pump,

前言

西貢區北港濾水廠建築工程混凝土中，採用大量煤灰，作爲膠結組分。濾水廠佔地九公頃，建成後，將成爲水務署17所濾水廠中的第二大廠。該水廠第一期工程於一九八九年六月完成，本報告描述該期工程。

工程內容

工程總值超過4.75億港元，包括興建濾水廠，泵站，主要水塘，5.9公里水道，1.2公里水管以及附屬景觀工程。

首期工程用煤灰混凝土6,500立方米，作爲廠房、溝渠涵洞、通道、高架水渠等，工項有防水構件、水池及濾水廠排水道等。

煤灰混凝土

工地採用各種混合比例拌成的煤灰混凝土，廠房及擋水堤用的大部份結構混凝土爲30/20級，粘合成份（普通水泥＋煤灰）至少爲360公斤/米^3。水/粘合物的最大比例爲0.5。

混合比例爲：每立方米混凝土含有385至430公斤膠結物（粘合物），其中煤灰佔25%，28天平均強度達到37－50兆帕。

混凝土澆注

煤灰混凝土事先拌好，用通常的混拌車裝運到現場。夏季採用調溫混凝土，以

depending upon the location, size and configuration of the individual pours. Four stationary tower cranes provided extensive coverage of the site. For large structural pours, several mobile concrete pumps were used in conjunction with the crane and skip placement method. Good early strengths were achieved, permitting specified shutter stripping time and turnround of formwork.

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例

Mix Grade	30/20	30/20
Cementitious Content	430	385
PFA (as % OPC + PFA)	25	25
Water/Cement Ratio	0.5	0.48
Aggregate/Cement Ratio	3.72	4.55
Admixture (1/m^3)	0.95	0.85
Slump (typical) (mm)	100	50
Compressive Strength (MPa)	47	40
28-Day Standard Deviation (MPa)	4.9	5.1

Why PFA?

PFA concrete was proposed in order to benefit from the lower heat of hydration, better workability and higher long-term strength than is normally achieved with OPC concrete. PFA concrete can also generally be expected to have lower long-term permeability and better durability than equivalent OPC mixes. The use of PFA concrete at Pak Kong also permitted savings in the materials cost of the concrete.

Placement of the PFA concrete was very successful, despite the relatively high cement content coupled with a low water: cement ratio, and the concrete has performed well in all the applications.

Conclusion

Pak Kong is an example of the hundreds of projects in Hong Kong where PFA concrete has proven to be popular among users for the technical and economic benefits it can provide.

Acknowledgements

Client:
Water Supplies Department, Hong Kong Government
Consulting Engineer:
Watson Haswell
Contractor:
Costain International Ltd (Contract 37/WSD/84)
Concrete Supplied by:
K Wah Concrete Ltd
Cement & PFA Supplied by:
China Cement (HK) Ltd

減少熱裂，並符合澆注溫度允許上限32℃的要求。

混凝土的澆注，則視各次澆注工事地點，規模及構型而定，採用吊車、箕斗、或者混凝土泵。地盤佈署四架固定塔式吊車。大型構築澆注時，則動用多台流動式混凝土泵，同時亦採用吊車抓斗法澆注。此種混凝土能在短期內獲得所需強度，有助更快拆除模板縮短模殼工程的時間。

煤灰優點

這次使用煤灰混凝土，取其優點，它與一般普通水泥混凝土相比，水化熱量低，拌和性好，遠期強度高，煤灰混凝土比同等普通水泥拌合料亦有較低的長期滲透性和較佳的耐久性，採用煤灰混凝土還可節省混凝土材料的成本。

這次澆注煤灰混凝土，十分成功；儘管水泥含量較高以及水與水泥拌合的比例較低，混凝土在各次使用中性能良好。

結論

煤灰混凝土在經濟及技術上具有不少優點，深受用戶歡迎，在數百項工程中，北港工程便是其中一項。

鳴謝：
客戶：港府水務署
諮詢工程師：Watson Haswell
承建商：Costain International Ltd.
(37/WSD/84號合約)
混凝土供應商：嘉華混凝土有限公司
水泥及煤灰供應商：中國水泥有限公司

China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*
147 Argyle Street, Kowloon, Hong Kong. Tel.: (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

PFA Structural Concrete used at Tsim Sha Tsui Cultural Centre

文化中心工程報告

Tsim Sha Tsui Cultural Centre under construction. 工程進行中的尖沙咀文化中心

Introduction

Since its opening in November 1989, the Tsim Sha Tsui Cultural Centre has made a significant impact on the cultural life of Hong Kong. It is the flagship in a series of six cultural centres either completed or under construction in various parts of the territory, under the auspices of the Architectural Services Department.

Over 50,000m^3 of concrete containing Pulverized Fuel Ash (PFA) were used in the construction of the superstructure and foundations of this prestigious complex.

The Project

Government awarded the contract for construction of the Tsim Sha Tsui Cultural Centre in October 1984. The cost of the entire project is around $500 million, to be shared by government and the Urban Council.

The contract for the civil engineering and superstructure work was awarded to Kumagai Gumi (Hong Kong) Ltd. This work involved construction of the 2,300 seat main auditorium, as well as additional buildings within the Cultural Centre separate from the auditorium proper and a pedestrian plaza linking with the Tsim Sha Tsui Promenade to provide a continuous walkway from the Star Ferry to Hung Hom.

Why PFA ?

PFA has been used successfully for many years worldwide in structural concrete as well as in other civil engineering applications. The commercial success of PFA derives from the benefits its specific physical and chemical properties provide endusers.

PFA has been used to advantage in virtually all classes of constructional concrete – including slipformed and prestressed concrete – as both a cement replacement and a grading improver.

Blended OPC/PFA cements and PFA neat can be used to replace 25% or more of the cement content of structural and mass concrete with worthwhile cost savings.

Following thorough evaluation of the cost and technical characteristics of conventional OPC and of OPC/PFA concrete, Kumagai Gumi as well as its consultant decided to use PFA concrete for all of the Cultural Centre's major structural work. There were valid reasons for Kumagai Gumi choosing PFA:

- Worthwhile cost savings were achieved
- Better workability and compactability due to PFA's sphericial particle shape were realised.
- Reduced heat of hydration, with a consequential reduction in cracking, was achieved.
- Excellent long-term strength durability and chemical resistance, – long a PFA hallmark – were appreciated from the outset.

On completion of concreting in

前言

尖沙咀文化中心已於1989年11月落成，在本港文化生活中起着重大作用。本港各區計劃，興建的六座文化中心，以其爲首。此座文化中心地基及上蓋工程中，共使用煤灰混凝土五萬多立方米。

工程內容

熊谷組於1984年10月承攬政府尖沙咀文化中心施工合約。工程耗資五億港元，由政府及市政局分擔。

熊谷組承建土木及上蓋工程，營造2,300個座位的大堂，副樓及行人廣場，啣接尖沙咀大道，由天星碼頭直達紅磡。

煤灰的功用

煤灰已在世界各地建築混凝土中以及其他土木工程用途方面成功地使用了許多年，煤灰在商業上取得的成功，歸因於其特殊的物理化學性能及多方面的優點。

煤灰實際上已有效地使用於所有級別的建築混凝土中，包括滑模施工混凝土和預應力混凝土，作爲水泥代用品和級別改良劑。

煤灰混凝土混合水泥淨煤灰可代替建築混凝土和大體積混凝土中25%以上的水泥成份，從而大大降低成本。

熊谷組對照普通混凝土及煤灰混凝土的料價及技術特性，基於下列理由選用煤灰混凝土營造各項結構主件工程：

- 料價大爲節省。
- 由於煤灰顆粒渾圓，混凝土拌和性及緻密度較好。
- 水化熱及熱裂有所削減。
- 遠期強度，耐久性及抗化學性優秀。

熊谷組混凝土工程於1985年竣工，工程經理指出煤灰混凝土料的優秀性，容易泵送修面，沒有技術問題；今後只要施工圖則許可，必定援引今次成功經驗，採用

The completed Cultural Centre. 文化中心竣工全景

1985, Kumagai Gumi's project manager described the PFA concrete as an excellent material and noted that easier pumping and finishing was achieved with no technical problems. On the basis of the experience gained on this project, he would not hesitate to use PFA concrete in future whenever the project specification permitted the use of PFA.

PFA Concrete

The majority of the 50,000m^3 of PFA concrete placed was a 30/20 structural grade pump mix with a 75mm slump which was used in the superstructure and the foundations of the Cultural Centre. The average 28-day strength of this mix was 46.7 MPa, with a standard deviation of 5.2 MPa.

Supply

PFA was sourced from Lamsonite Company Limited and batched by Pioneer Concrete (Hong Kong) Ltd.

Pioneer Concrete has been an advocate for the broader use of PFA since the material first became available commercially in the early 1980s. The company promotes the use of PFA concrete wherever feasible, primarily because it is easy to pour and place. Quality assurance and quality control pose no problems when site workers are properly briefed and supervised.

Conclusion

The Tsim Sha Tsui Cultural Centre is one of many prestigious building projects where PFA has been well accepted in structural concrete as a wise engineering choice for both economic and technical reasons.

Others include the government office complex on Harbour Road, and key infrastructural projects such as the Pak Kong Water Treatment Works, the Eastern Harbour Crossing, Route 5, and the Mass Transit Railway.

Ackowledgements

Client:
Urban Council
Architect:
Architectural Services Department, Hong Kong Government
Consultant:
Ho – Happold Consulting Engineers
Contractor:
Kumagai Gumi (Hong Kong) Ltd (Contract No. 418/AO/1984)
Concrete Supplier:
Pioneer Concrete (Hong Kong) Ltd
PFA Supplier:
Lamsonite Company Limited

煤灰混凝土。

煤灰混凝土

文化中心基礎及上蓋工程中澆築五萬立方米煤灰混凝土，如30/20級配泵送75毫米塌方，28天強度平均46.7兆帕，標準偏差5.2兆帕。

配料則見附表。

自從煤灰在80年代初首次用於商業方面後，派安混凝土公司便廣泛推廣煤灰的使用。該公司在所有可能範圍之內均用煤灰，主要是由於煤灰易於澆注和灌漿。只要對場地工人教育和加以適當監督，品質保證和品質控制均無問題。

供料：

工程煤灰料由隆順有限公司供應，派安混凝土香港有限公司現拌。

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例

Mix Grade	D30/20
O.P. Cement	320
PFA	110
(% OPC + PFA)	25
CRF	605
14mm Granite	430
20mm Granite	640
Water	195
Admixture	0.86
Slump (mm)	75
Compressive Strength (MPa)	
28-day	46.7
28-Day Standard Deviation (MPa)	5.2

自從煤灰在80年代初首次用於商業方面後，派安混凝土公司便廣泛推廣煤灰的使用。該公司在所有可能範圍之內均用煤灰，主要是由於煤灰易於澆注和灌漿。只要場地工人可靠和加以適當監督，品質保證和品質控制均無問題。

結論

本港多項重要工程基於經濟及技術理由大多選用煤灰，尖沙咀文化中心實爲此明智選擇例證。

其中包括港灣道政府合署和一些重要基礎工程，北港濾水廠，東區海底隧道和地下鐵路便是其中例子。

鳴謝：

客戶：
市政局
建築師：
香港政府建築署
結構工程師：
何合保工程顧問
承建商：
熊谷組（香港）有限公司
（合約418/AO/1984）
料商：
派安混凝土（香港）有限公司（混凝土料）
隆順有限公司（煤灰料）

China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*
147 Argyle Street, Kowloon, Hong Kong. Tel : (852) 760 6111 Telex: 51555 FUSUP HX Facsimile: (852) 760 1884

Harbour Road Govt. Offices Constructed with PFA Concrete
煤灰混凝土在港灣道政府合署的應用

Government Offices under construction. 工程進行中的政府合署

Introduction

Large quantities of Pulverized Fuel Ash (PFA) were used in the concrete for Phases I and II of the government office complex now rising on Harbour Road. When completed in 1992, the complex will comprise three 49-storey tower blocks having a gross floor area of 108,000m^3 to house various government departments. Additional structures include a basement car park, fire station, district court and magistracy, science building and a landscaped plaza.

The Project

The contract for Phase I of the nearly $2 billion complex was awarded to Kumagai Gumi (Hong Kong) Ltd in December 1982. Valued at $240 million, the Kumagai Gumi contract called for the construction of a two-level basement and foundation on reclaimed land. Work was completed in 1985.

The Phase II contract was awarded to Shun Shing Construction and Engineering Company Limited. This contract, valued at $318 million, involved constructing the complex's first 49-storey tower.

Why PFA ?

PFA has been used successfully for many years worldwide in structural concrete as well as in other civil engineering applications. The commercial success of PFA derives from the benefits its specific physical and chemical properties provide endusers.

PFA has been used to advantage in virtually all classes of constructional concrete – including slipformed and prestressed concrete – as both a cement replacement and a grading improver.

Blended OPC/PFA cements and PFA neat can be used to replace 25% or more of the cement content of structural and mass concrete with worthwhile cost savings.

Following thorough evaluations of a conventional OPC and of OPC/PFA concrete, both Kumagai Gumi and Shun Shing, as well as their consultants, decided to use PFA concrete for the following reasons:

- PFA concrete offers long-term durability and strength gain
- PFA's spherical particle shape improves the workability and pumpability of concrete
- PFA lowers heat of hydration

前言

港灣道政府合署工程首期及第二期工程，使用大量煤灰混凝土。合署由三座49層樓組成，樓面面積總計108,000立方米，容納政府各部門，預計在1992年落成，附設地下停車場、消防局、地區法院、律政署、科學樓及花園廣場。

工程內容

合署總值廿億；熊谷組香港有限公司於1982年12月取得工程合約，在新填地上建設樓基及雙層地下車場，1985年完成。

順成建築工程有限公司負責第二期工程，價值3.18億港元，建設首座49層樓大廈。

煤灰的功用

煤灰已在世界各地的建築混凝土中以及其他土木工程用途方面成功地使用了許多年，煤灰在商業上取得的成功，歸因於其特殊的物理及化學性能及多方面的優點。

煤灰實際上已被有效地使用於所有級別的建築混凝土中，包括滑模施工混凝土和預應力混凝土，作爲水泥代用品和級別改良劑。

煤灰/混凝土混合水泥和淨煤灰可代替建築混凝土中25%以上的水泥成份，從而大大降低成本。

熊谷組和瑞興聯同其工程顧問對普通混凝土及煤灰混凝土作出評估後一致決定


Early stages of construction. 早期施工景象

and reduces thermal cracking
Both contractors also realised worthwhile material cost savings by using the PFA concrete
These features proved especially beneficial for the concrete pours by Kumagai Gumi, one of which had a volume of 3336m^3, at that time the largest-ever single concrete pour made in Hong Kong. In all, Kumagai Gumi used in excess of 150,000m^3 of a 30/20 structural grade PFA concrete in the top down construction technique adopted for construction of the foundation.

The total volume of PFA concrete used by Shun Shing was around 50,000m^3, with PFA accounting for 25% of the cementitious component. A grade 40/20 concrete was used in all structural elements of Tower I, while the ground slabs and basement utilised a 30/20 mix.

Concrete was placed, under both contracts, using boom pumps and conveyors.

Supply

PFA used by Kumagai Gumi and Shun Shing was supplied by Lamsonite Company Limited and the concrete was supplied by Pioneer Concrete (Hong Kong) Ltd.

Quality assurance and quality control posed no special problems as site workers were properly briefed and supervised on the use of the material.

Both the contractor and the concrete supplier commented that they would not hesitate to use PFA concrete in future whenever project specifications permitted.

Conclusion

The Hong Kong Government complex is one of many prestigious building projects where PFA has


Building nearing completion. 合署接近竣工全景

been well accepted in structural concrete as a wise engineering choice for both economic and technical reasons.

Others include the Tsim Sha Tsui Cultural Centre, and key infrastructural projects such as the Pak Kong Water Treatment Works, the Eastern Harbour Crossing, Route 5, and the Mass Transit Railway.

Ackowledgements

Client:
Architectural Services Department, Hong Kong Government
Consultants:
Maunsell Consultants Asia
Contractors:
Kumagai Gumi (Hong Kong) Ltd. (Contract 227/AO/82)
Shun Shing Construction & Engineering Co Ltd (Contract SS 6513)
Concrete Supplier:
Pioneer Concrete (Hong Kong) Ltd
PFA Supplier:
Lamsonite Company Limited

採用煤灰混凝土，理由如下：

- 煤灰混凝土強度較高，而且耐久。
- 煤灰顆粒渾圓，混凝土拌和性及泵送性較好。
- 煤灰有效削減熱裂及水比熱量。

兩家承建商均採用煤灰混凝土，成本大爲節省。

熊谷組混凝土樓基工程，單次澆築量高達3,336立方米，創當時全港記錄，實有賴於煤灰粉。頂灌法築基施工煤灰混凝土（30/20級配），用量超過15萬立方米。

順成採用5萬立方米煤灰混凝土，煤灰佔其膠結組份四分之一。A座大廈構件全部採用40/20級配混凝土，埋板及地台則爲30/20料合混凝土。

兩期合約均用吊泵及輸送機澆築混凝土。

供料：

熊谷組及順成煤灰料由隆順有限公司供應，派安混凝土香港有限公司現拌。

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例

Mix Grade	D30/20	D30/20
O.P. Cement	305	355
PFA	95	115
(% OPC + PFA)	25	25
River Sand	535	455
14mm Granite	415	420
20mm Granite	765	780
Water	190	190
Admixture	0.80	0.94
Slump (mm)	75	75
Compressive Strength (MPa)		
28-day	41	50.7
28-Day Standard Deviation (MPa)	4.5	4.5

結論

本港多項重要建築工程鑒於經濟及技術原因，多用煤灰，港灣道政府合署爲此明智選擇例證。

其中包括尖沙咀文化中心和一些重要基礎工程，諸如北港食水處理廠、東區海底隧道和地下鐵路。

鳴謝：

客戶：
香港政府建築署
顧問：
茂盛工程顧問有限公司
承建商：
熊谷組（香港）有限公司
（合約號227/AO/82）
順成建築工程有限公司
（合約號：SS6513）
料商：
派安混凝土（香港）有限公司（混凝土料）
隆順有限公司（煤灰粉料）

Use of PFA a factor in early completion of Tate's Cairn Tunnel

採用煤灰混凝土是提前完成 大老山隧道工程的重要因素之一

Introduction

The opening of the Tate's Cairn Tunnel in July 1991 was a milestone in the development of transport infrastructure in Hong Kong. The tunnel is the fifth driven road tunnel to be completed in the territory and serves as a vital link on Route 6, a major transport artery connecting the northeast part of the New Territories with East Kowloon and Hong Kong Island.

Large quantities of concrete containing Pulverized Fuel Ash (PFA) were used on the $2.15 billion project in the construction of the tunnel lining, ventilation shafts, walkways, approach road network and administration buildings. In all, 297,500m^3 of PFA concrete were specified by the constructor and civil engineering consultant.

The Tate's Cairn Tunnel, which is one of the major road tunnels of South East Asia, was completed in three years – a significant achievement for such a large civil engineering undertaking.

The Project

The contract to construct the Tate's Cairn Tunnel was awarded by the Tate's Cairn Tunnel Company (TCTC) to the Gammon-Nishimatsu Joint Venture (GNJV) in July 1988 on a design and construct basis. The TCTC franchise offer, which was based on the GNJV bid, was preferred largely because the design and construction methods it suggested for the civil engineering and other work realised substantial cost savings and allowed the quickest possible completion period. These methods were derived in conjunction with Maunsell Consultants Asia Ltd.

The project called for the construction of twin, dual-lane carriageway tunnels between the Diamond Hill area of northeast Kowloon and the Siu Lek Yuen area of Sha Tin together with approach roads linking the tunnel into the road system in both areas.

The 4km tunnel has a high point in the centre and falls gradually to the portals to facilitate drainage. It is approximately 400m below ground where it passes under the spur between the peaks of Tate's Cairn and Temple Hill. The distance between portals – 3913m northbound and 3945m southbound – makes it the longest tunnel in Hong Kong.

Support and lining for the Tate's Cairn Tunnel include rock bolting, shotcreting and a nominal 300mm thick mass concrete permanent lining. The as-struck tunnel lining is painted to form the finished surface.

Early stages of Tate's Cairn tunnelling work. 早期工程中的大老山隧道。

簡介

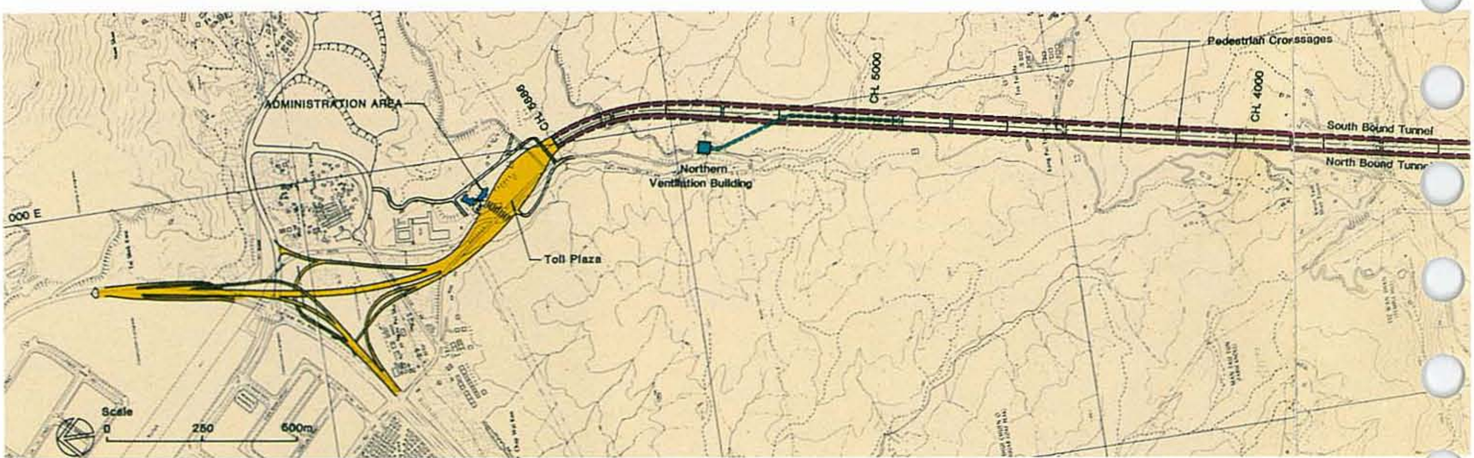
一九九一年七月大老山隧道的開放是香港交通運輸發展的一個里程碑。該隧道是在香港建成的第五條行車隧道，而且是六號幹綫公路的重要部份。（註：六號公路是連接新界東北部與東九龍及港島的主要交通幹綫。）

在這項耗資21.5億港元的工程中，隧道牆身架、通風井、行車道、銜接道路網和行政大廈的施工採用了大量含有煤灰(PFA)的混凝土。承建商及土木工程顧問公司指定使用總量達二十九萬七千五百立方米的煤灰混凝土。

作爲東南亞主要行車隧道之一的大老山隧道在三年內完工，是同類大型土木工程的一項重大成就。

大老山隧道工程

一九八八年七月金門與西松組成的 Gammon-Nishimatsu Joint Venture (GNJV) 公司獲得大老山隧道的營造合約，這是一種建造——經營——移交的合約。在六個投標中，GNJV 公司的投標被選中，這是因爲 GNJV 與 Maunsell



Why PFA?

For the concrete tunnelling work, GNJV had to strike a careful balance between early strength attainment for the concrete mix and the need to keep shrinkage and heat of hydration to an absolute minimum. Following careful evaluation of conventional OPC concrete and of PFA concrete, GNJV opted for the latter. A number of trial mixes were tested. Mix proportions decided upon are shown in the table.

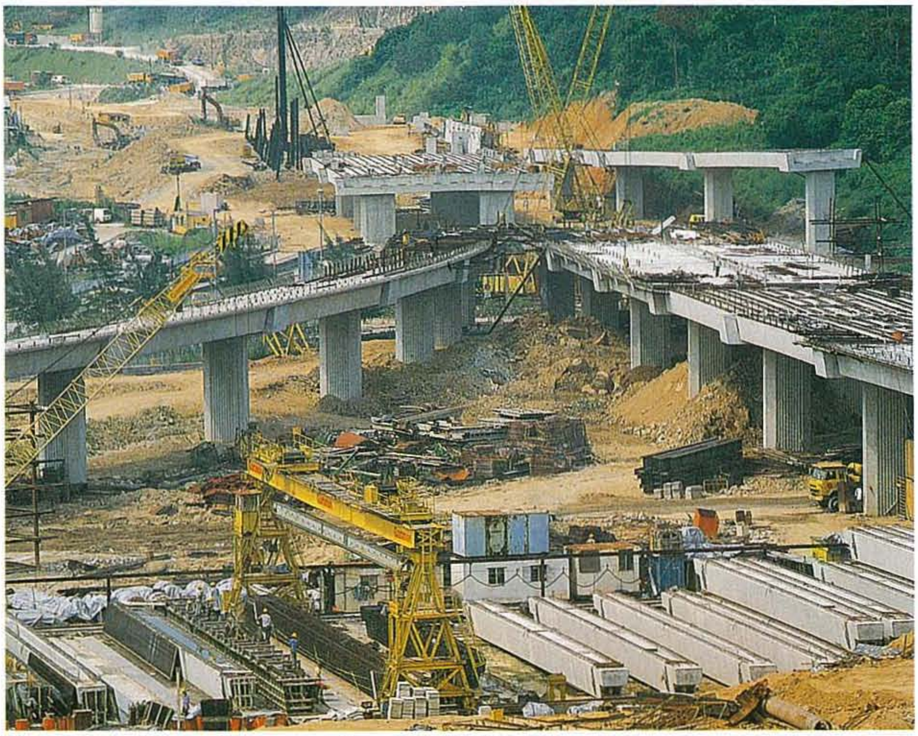
Approximately 110,000m^3 of PFA concrete were used in the tunnel and tunnel linings at Tate's Cairn. Placement was by concrete pumps. Due to the reduction in shrinkage cracking achieved with PFA, up to 33% of the material was used as a cementitious component in some elements.

It is significant that GNJV was able to strike the tunnel formwork within 16 hours of casting. "V" notches were cast in the tunnel lining at 2.4m centres to induce preferential cracking. Shutters were struck hydraulically and moved on to their next location.

For the 7km of approach roads, some 87,500m^3 of PFA concrete were used to the standard Highways Department specifications. Another 100,000m^3 were used in the elevated road structures, footbridges and administration buildings.

In using PFA at Tate's Cairn, GNJV reaped the following benefits:

- Reduced heat of hydration, with a consequent reduction in cracking.
- Better workability and compactability due to PFA's spherical particle shape.
- Excellent long-term strength, durability and chemical resistance.
- Significant cost savings.



Overall view of the northern approach roads. 北面引道一覽。

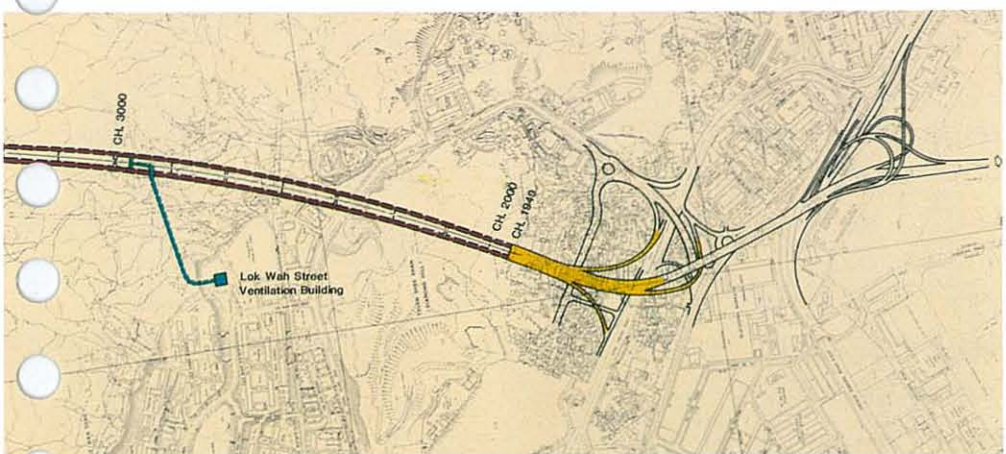
Supply

PFA used at Tate's Cairn was sourced from China Cement Company Limited and Kin Ching Ash Ltd classified to a specification which met BS 3892 : Part 1.

Concrete for the tunnel was supplied jointly by Gammon Construction Ltd and Ready Mixed Concrete (HK) Ltd. Gammon also supplied the concrete for the elevated structures and roads in the approaches to the tunnel.

Quality assurance and quality control posed no special problems as site workers were properly briefed and supervised on the use of PFA concrete.

Upon completion of the tunnel project GNJV commented that they were entirely satisfied with the properties of PFA concrete as demonstrated in the applications in



Consultants Asia Ltd 工程顧問公司共同研究的工程設計和施工方法可實現大規模減省成本並且可得到最短的工程施工時間。

該大老山隧道工程要求建造位於九龍東北部鑽石山地區與沙田小瀝源之間的兩管雙綫隧道以及連接隧道與兩個地區道路網的引道。

四公里長隧道的最高點位於中心處，然後向兩個隧道口逐漸下降以利於排水通風。隧道在地下 400 米處穿過大老山峯與慈雲山峯之間的山嘴。兩個隧道口之間距離……北行管道長 3913 米，南行管道長 3945 米——因而是香港最長的隧道。

大老山隧道的支承和牆身架包括有鞏固石錨、噴漿和300毫米厚的混凝土永久性牆身架。而在隧道牆身架面上掃漆以形成光潔表面。

爲什麼採用煤灰？

在隧道混凝土施工方面，GNJV 公司需要小心平衡混凝土的較高早期強度及盡量減少混凝土收縮和水化熱等要求。對普通水泥混凝土和煤灰混凝土仔細比較之後，結果 GNJV 選用了後者。試驗了若干混凝土混合料。下表列出所採用的混凝土料混合比例。

大老山隧道及其牆身架使用了大約十一萬立方米煤灰混凝土。用混凝土泵澆注混凝土。由於採用煤灰而使收縮開裂減少，在一些構件中採用了多達 33%的煤灰作爲膠結料。

重要的優點是 GNJV 公司能夠在澆槳後 16 小時內拆下隧道模板。在隧道牆身架每隔 2.4 米就澆成一個"V"形槽以誘發冷熱收縮裂位。模板用液壓裝置拆除並移到下一個位置上。

在七公里長行車引道中使用了大約八萬七千五百立方米煤灰混凝土，這種混凝土達到了路政署的規範。在高架道路結

The precast beam fabrication yard. *預先安裝橫樑場地。*

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例。

	Tunnel Lining	Carriageway
Mix Grade	**30/20**	**30/20**
Cementitious Content (kg/m³)	330	360
PFA (as % OPC + PFA)	25	25
Water/Cement Ratio	0.59	0.49
Aggregate/Cement Ratio	5.4	4.9
Admixture (l/m³)	1.4	1.5
Slump (typical) (mm)	100	25
Compressive Strength (MPa)	38.3	49.9
28-Day Standard Deviation (MPa)	5.7	5.5

which it was specified throughout this massive project.

Conclusion

PFA has been used successfully for many years in structural concrete, including slipformed and prestressed concrete.

The Tate's Cairn Tunnel is one of a growing number of Hong Kong infrastructural projects where PFA concrete has been shown to be a wise engineering choice for sound economic and technical reasons in structural concrete. Other recent infrastructural projects which have used PFA concrete are Route 5 and the Eastern Harbour Crossing. Many prestigeous buildings, including Central Plaza, the world's tallest reinforced concrete structure, and Cityplaza Phases 3 & 4 also have been built using PFA concrete.

Acknowledgements

Client:
Tate's Cairn Tunnel Company Limited
Consultant:
Maunsell Consultants Asia Ltd
Independent Engineers:
Scott Wilson Kirkpatrick & Partners
Contractor:
Gammon-Nishimatsu Joint Venture
Concrete Suppliers:
Ready Mixed Concrete (HK) Ltd
Gammon Construction Limited
PFA Suppliers:
China Cement Company Limited
Kin Ching Ash Ltd

構、行人天橋和行政大廈中另外使用了十萬立方米。

GNJV 公司在大老山隧道中採用煤灰獲得下列益處：

- 降低了水化熱從而使開裂減少。
- 球粒狀煤灰提高了混凝土的易拌性及壓實性。
- 優異的遠期强度、耐久性及耐化學腐蝕性。
- 顯著地節省成本。

供應來源

大老山隧道的煤灰由Kin Ching Ash Ltd 供應；這些煤灰達到英國標準BS3892：Part I。

隧道用的混凝土由 Gammon Construction Ltd 和 Ready Mixed Concrete (HK) Ltd 共同供應。前者還供應用於隧道引道系統的高架道路結構和其他道路的混凝土。

品質保證和品質控制方面並沒有特別的問題，因爲已向地盤工人說明如何使用煤灰混凝土並對工人的工作實施了適當的監管。

隧道工程完工後，GNJV 評論說他們對煤灰混凝土在指定應用中表現的性能感到十分滿意。

結論

許多年來，煤灰已成功地應用在結構混凝土中(包括滑模及預應混凝土)。

大老山隧道是香港日益增多的基礎設施之一；而在這項工程之中煤灰混凝土應用於結構混凝土而得到經濟和技術的效益足以證明這是明智選擇。近期已採用煤灰混凝土的其他基礎設施有五號幹線公路和東海底隧道。其他近期宏偉的建築包括中環廣場(世界上最高的鋼筋混凝土建築物)以及太古城中心第三及第四期亦採用煤灰混凝土建造。

鳴謝：

客戶：
大老山隧道有限公司
顧問公司：
Maunsell Consultants Asia Ltd
獨立工程師：
Scott Wilson Kirkpatrick & Partners
承建商：
Gammon-Nishimatsu Joint Venture
混凝土供應商：
Ready Mixed Concrete (HK) Ltd
Gammon Construction Limited
粉煤灰供應商：
China Cement Company Ltd
Kin Ching Ash Ltd

High strength PFA mix used at Cityplaza 3 and 4

太古城中心第三及第四期工程採用了高強度煤灰混凝土

Introduction

A special high strength concrete mix incorporating Pulverized Fuel Ash (PFA) proved to be the most efficient engineering solution to the challenges encountered when designing and constructing Cityplaza 3 and 4.

Located at Taikoo Shing, Cityplaza 3 and 4 consist of two 22-storey Grade A office buildings connected by a pedestrian bridge to the Cityplaza shopping centre. They are being completed out of numerical sequence. Cityplaza 4 opened in December 1991 and Cityplaza 3 in March 1992. The total gross floor area of the two buildings is 102,000m^2.

Dragages et Travaux Publics (HK) Ltd was awarded the $732 million contract to undertake construction of this project owing to the company's many local and worldwide references in adopting innovative techniques for post-tensioned reinforced concrete structures.

The Project

Cityplaza 3 and 4 are located on either side of an access road to the Island Eastern Corridor and adjacent to the future Quarry Bay Park. As the two buildings are sited along the flight path to and from Kai Tak International Airport, height

簡介

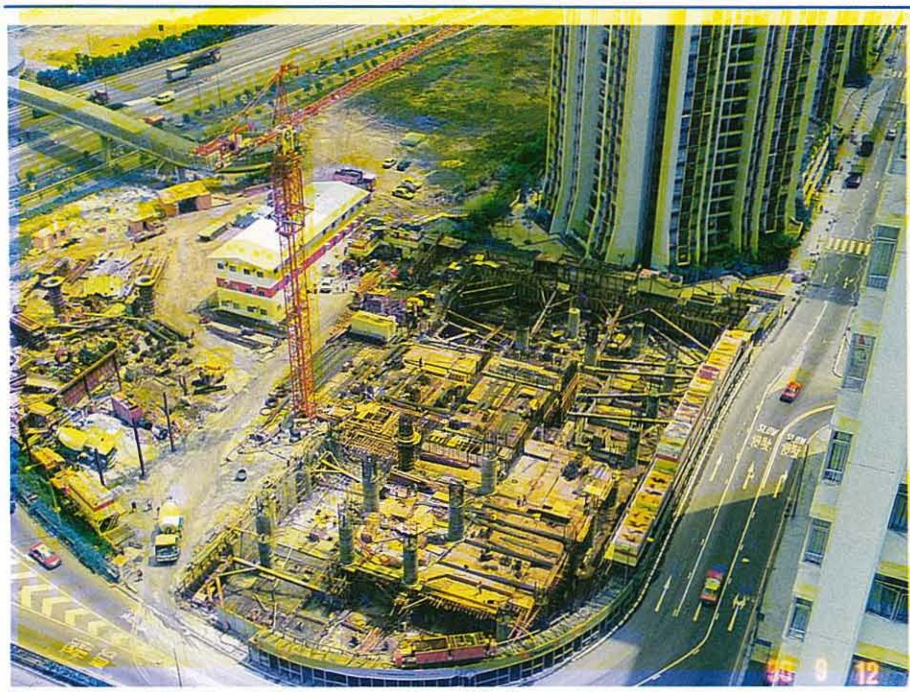
採用特種高强度煤灰混凝土已證實是解決太古城中心第三及第四期工程設計與建造的最有效工程技術方案。

太古城中心第三及第四期由兩座二十二層A級寫字樓組成，寫字樓由行人天橋連接到鄰近的太古城購物商場。然而其落成先後次序是不同的。太古城中心第四期已於一九九一年十二月開放而太古城中心第三期亦於一九九二年三月開放。兩座大廈的總樓面面積爲十萬零二千平方米。

法國濬海及公共建築公司獲得該項價值7.32億港元的建造合約，因爲該公司在應用革新的後加應力鋼筋混凝土結構技術，不論在本港或世界各地均擁有豐富經驗。

工程

太古城中心第三及第四期位於港島東



General view of Cityplaza 4 during construction of the basement.
建造中的太古城中心第四期地庫全景。

restrictions were imposed by the Civil Aviation Department. The reinforced concrete columns therefore had to be sized so that the maximum lettable floor area could be achieved in the limited height space permitted by the CAA.

Both Ordinary Portland Cement (OPC) concrete and PFA concrete were considered. Following thorough evaluation of the two, Dragages, in consultation with its consultants, Ove Arup & Partners, decided on a specially designed PFA concrete for Levels 4 through 17. Use of PFA concrete was accepted by the Buildings Ordinance Office on this project due to its engineering qualities.

Why PFA?

PFA concrete has been used successfully for many years worldwide in structural concrete owing to the benefits its specific physical and chemical properties provide users. These properties proved crucial in meeting the special challenges that arose in the design and construction of the reinforced concrete columns at Cityplaza 3 and 4.

Use of conventional OPC concrete was ruled out for two reasons. First, its high cement content results in increased heat of hydration. This problem could be overcome by installing a water cooling system but, after tests, Dragages found this to be

Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例。

Mix Grade	D60/10
Cementitious Content (kg/m³)	435
PFA (as % OPC + PFA)	22
Water/Cement Ratio	0.31
Aggregate/Cement Ratio	3.92
Admixture (l/m³)	3.40
Slump (typical) (mm)	150
Compressive Strength (MPa)	
7-day	55
28-day	73.8

區酒廊其中一個入口的兩旁，並靠近未來的鰂魚涌公園。由於兩座大廈位於來往啓德國際機場的飛行路徑上，故其高度受到民航處的限制。因此，在民航處允許的高度範圍內，必須考慮鋼筋混凝土柱的設計以便設法盡量增大可出租的樓面面積。

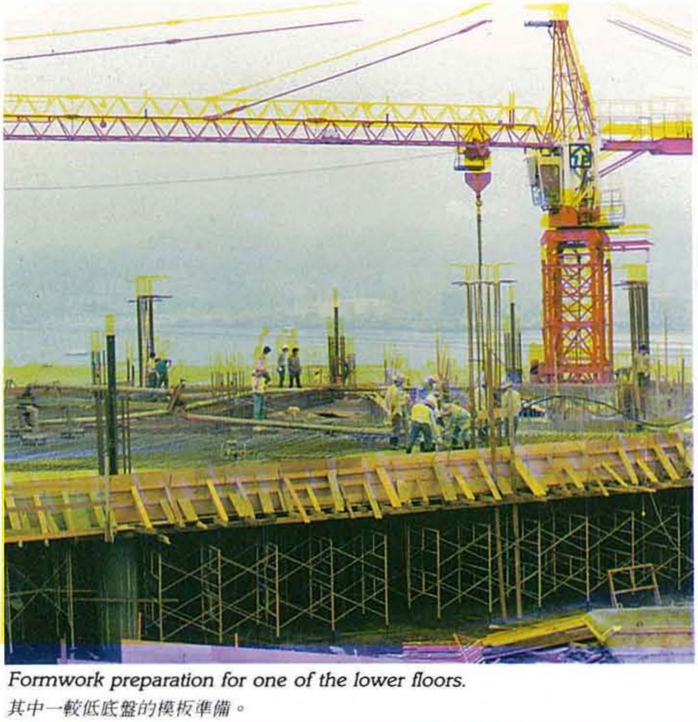
Dragages 公司深入分析普通水泥混凝土及煤灰混凝土，該公司與其顧問公司 Ove Arup & Partners 商量之後決定在大廈的第四層至第十七層採用特別設計的煤灰混凝土。由於煤灰混凝土擁有良好工程質量，建築物條例執行處同意在該工程中使用這種混凝土。

爲什麼採用煤灰？

世界各地的結構混凝土多年來已成功地採用煤灰混凝土，這是由於其特殊物理與化學特性能爲用戶帶來益處。這些特性正好是太古城中心第三及第四期工程鋼筋混凝土設計及施工所要求的重要因素。

由於兩個原因而決定不採用普通混凝土。首先，由於其水泥含量高，因而水化熱較高，雖然安裝水冷却系統可解決這個問題，但是，經過試驗後 Dragages 公司發現這樣做的成本太高，而同樣重要的問題是，這種混凝土不能配合緊迫施工進度的要求。每層樓面的規定建造時間只有四日。

選擇煤灰混凝土而不用普通混凝土的第二個原因是易拌性。在混凝土柱施工



Formwork preparation for one of the lower floors.
其中一較低底盤的模板準備。

Cityplaza 4 nearing completion.
太古城中心第四期接近完成。

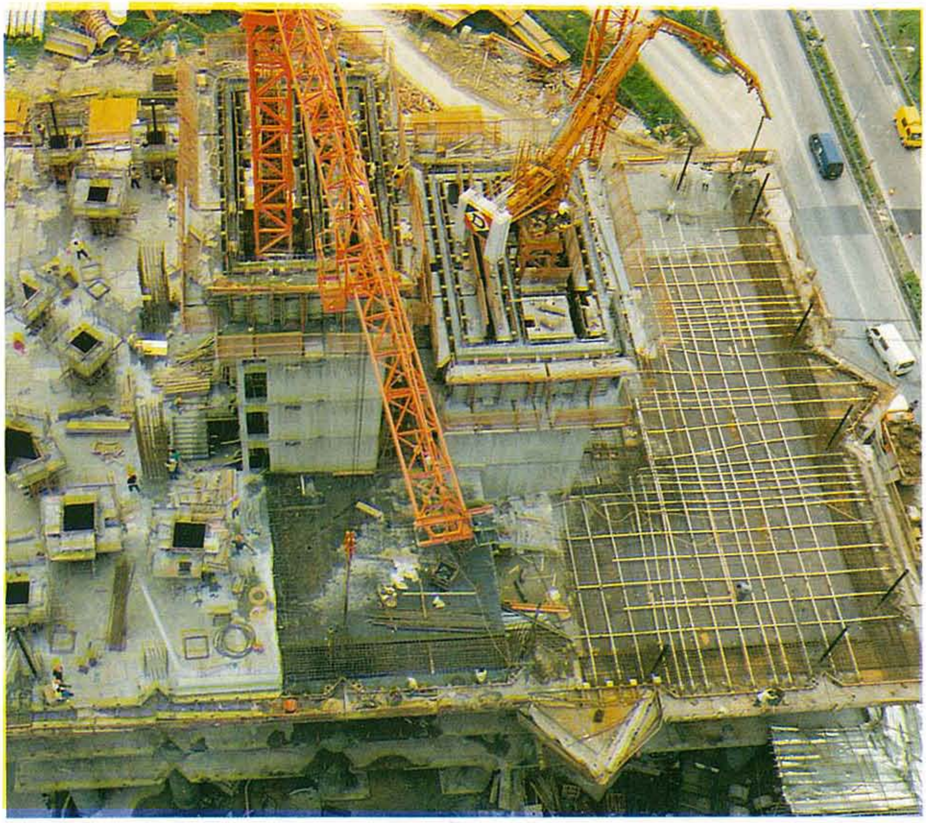
too costly and, no less important, incompatible with the tight time frame (4 days) allotted for the construction of each floor level.

The second reason for choosing PFA concrete over OPC concrete concerned workability. In constructing the columns, Dragages found the short setting time and lower workability of conventional OPC concrete to be distinct disadvantages.

To obtain the reduced heat of hydration and high workability required, Dragages opted for a high strength PFA concrete. After thorough testing, the mix decided on had a nominal strength of 60 MPa and an actual strength in the range of 80 MPa.

To ensure strength continuity in the concrete columns, a post-tensioning system was adopted which allowed a minimum strength of 25 MPa at less than 36 hours, even in cold weather. This early strength gain was a critical factor as it allowed the tendons to be stressed in time for stripping of the formwork. Due to the critical time constraints, it was necessary to precisely ascertain the required concrete strength of each pour before tensioning could start.

Commencing concrete placement at Cityplaza 3. *太古城中心第三期開始澆注混凝土。*



Aerial view of concrete placement at Cityplaza 4. *太古城中心第四期混凝土澆注俯覽景。*

中，Dragages 公司發現，普通混凝土凝固時間短及易拌性較低是重大的缺點。

爲了減少水化熱和獲得所需的高和易拌性，Dragages 公司選擇了高强度煤灰混凝土。經過全面的試驗，決定採用的混凝土料具有 60MPa 標稱强度及 80MPa 左右的實際强度。

爲了確保整個混凝土項的强度連續性，採用後加應力混凝土，這種混凝土能在不足36小時內(甚至在寒冷天氣中)最少達到25MPa的强度。獲得此種早期强度十分重要，因爲這樣便可盡早爲鋼筋加應力以便脫模。由於緊迫的時間限制，有必要在加應力之前準確地確定每次澆築的混凝土是否已達到所要求的强度。

Dragages 公司沒有採用壓磚方法來測定混凝土强度，而採用複雜的量度試驗以測定溫度與齡期之間相互關係。

煤灰混凝土的使用

在建造太古城中心第三及第四期混凝土柱中 Dragages 公司使用了大約三千五百立方米煤灰混凝土。附表列出混合料的詳細資料。

採用泵和澆注臂澆築至85米高度。

Cityplaza 3 and 4 fully completed. 太古城中心第三及第四期完竣全景。

Rather than measuring concrete strength by cube crushing, Dragages instituted a system under which the inter-relationship between temperature and age were measured after implementing sophisticated calibration tests.

PFA Concrete

Approximately 3500m³ of PFA concrete were used by Dragages in constructing the columns at Cityplaza 3 and 4. Mix details are shown in the table.

Placing was by pump to heights of 85m and by placing boom.

PFA Concrete Supply

Dragages sourced its PFA concrete from the Ap Lei Chau plant of Pioneer Concrete (HK) Ltd.

Conclusion

Cityplaza 3 and 4 are further examples of prestigious Hong Kong building projects where PFA concrete has been shown to be an ideal engineering solution to a significant structural concrete challenge. Others include the Cultural Centre, Hong Kong Government Wanchai Offices, and Central Plaza, the world's tallest reinforced concrete structure.

Acknowledgements

Client:
Swire Properties Ltd
Contractor:
Dragages et Travaux Publics (HK) Ltd
Architect:
Wong Tung & Partners
Consultant:
Ove Arup & Partners
Concrete Supplier:
Pioneer Concrete (HK) Ltd
PFA Supplier:
Lamsonite Company Ltd

煤灰混凝土供應來源

Dragages 公司由 Pioneer Concrete (HK) Ltd. 的鴨脷洲廠供應煤灰混凝土。

結論

太古城中心第三及第四期是香港採用煤灰混凝土的宏偉建築工程的另一實例；在此工程中煤灰混凝土已證實是滿足重要結構混凝土要求的理想物料。其他應用實例包括文化中心、香港灣仔政府合署以及中環廣場等，後者是世界最高的鋼筋混凝土建築物。

鳴謝

客戶：
Swire Properties Ltd
承建商：
Dragages et Travaux Publics (HK) Ltd
建築師：
Wong Tung & Partners
顧問公司：
Ove Arup & Partners
混凝土供應商：
Pioneer Concrete (HK) Ltd
煤灰供應商：
Lamsonite Company Ltd

High strength 60MPa PFA Concrete specified for Central Plaza
中環廣場：60MPa高強度煤灰混凝土

Introduction

Central Plaza has the distinction of being, at 374 metres, the world's tallest reinforced concrete building. It also has the distinction of being the first private sector building in Hong Kong constructed using a high-strength concrete mix incorporating Pulverized Fuel Ash (PFA). The 78-storey commercial building has been developed by a joint venture comprising Sun Hung Kai Properties Ltd, Sino Land Co Ltd and Ryoden Property Development Co Ltd.

In addition to its engineering distinctions, Central Plaza also has dominantly aesthetic features. It is triangular in plan, a rarity for office buildings anywhere in the world. Dictated by its location on the Wanchai waterfront, a triangular design was seen to be the most efficient way to maximise lettable floor space offering much sought after scenic views. Even by the standards of Hong Kong, this latter point assumed unusual importance for the developers, whose land costs totalled $3,350 million, the highest sum ever paid up to that time (1989) in Hong Kong.

Interest on the land alone amounted to $918,000 per day. Hence, the architects, consultants and in-house contractor engaged on the project were under great pressure to get the building open as quickly as possible without compromising the developer's stringent quality standards.

The Project

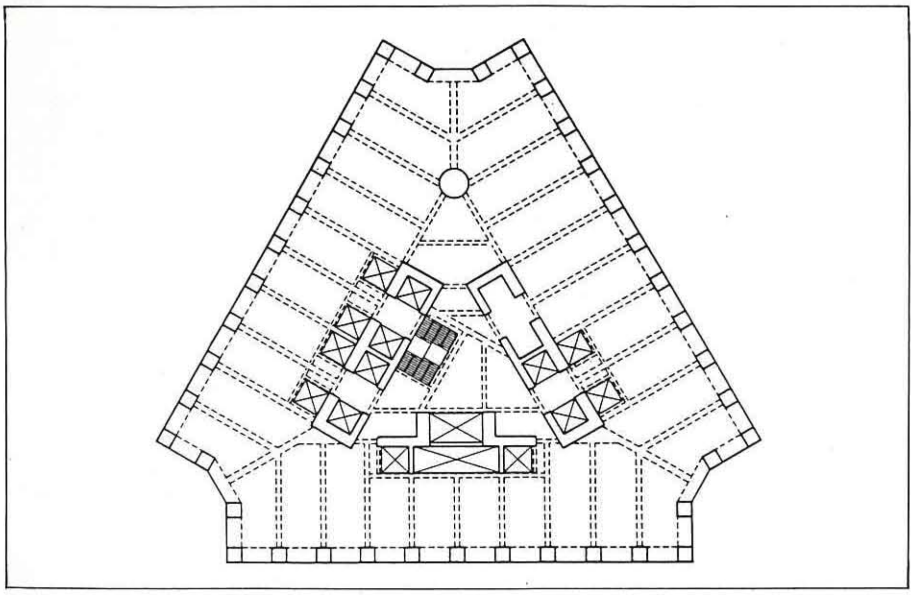
Central Plaza was originally designed to be a structural steel complex with curtain walling. A review of projected costs for a steel building prompted the designers to switch to a reinforced concrete building. This switch reduced across-the-board building costs substantially – from $1.6 billion to $1 billion. It also did away with the developer's qualms about possibly unsightly steel braces, and the restraints the use of steel places on design flexibility. Bearing in mind that a detailed building services design had not been finalised when construction commenced, maximum flexibility was required to cope with anticipated change.

In opting for reinforced concrete, the designers were able to increase the floor area from approximately 1935m^2 to 2215m^2. This lowered the building somewhat, but the large floor areas were more desirable to big tenants.

A fast construction rate was achieved using reinforced concrete. On average, one floor was completed every 4½ days. As pumping concrete to a height of 308m (most probably the highest in the world) was required, a system consisting of three stationary pumps, three sets of pipelines and three sets of placing booms was designed especially for the project.

Construction was in three phases (excluding the foundation and three basement levels). Phase 1 encompassed the ground level to the 27th floor, Phase 2 the 28th to 45th floor, and Phase 3 the remaining office floors, five mechanical plant floors and the sky lobby. Beyond the sky lobby, the tower top consists of

Typical tower floor plan. 某層樓面圖則。



Typical mix details for PFA concrete.
煤灰混凝土拌合資料一例。

Concrete grade	**D60/20**
Cementitious content (kg/m^3)	420
PFA (as % OPC + PFA)	24
Water/Cement Ratio	0.33
Aggregate/Cement Ratio	4.02
Admixture (1/m^3)	3.64
Slump (typical) (mm)	150
Compressive strength (MPa)	
7-day	50.8
28-day	75.6

前言

中環廣場樓高374米，是世界最高的鋼筋混凝土大廈。它亦是香港採用高强度煤灰混凝土的第一座私營樓宇。該座78層樓的商業大廈是新鴻基地產發展有限公司、信和地產投資有限公司和菱電地產發展有限公司的合資項目。

中環廣場除了工程上的特點之外，外觀方面亦超羣出衆，其平面呈三角形狀，在全世界各地辦公大樓中是絕無僅有的設計。由於受灣仔海傍附近地形限制，三角形設計看來是獲得最大可出租樓面面積的最有效方案。即使以香港地產發展的標準來衡量，這個理由對發展商來說也是極重要的，因爲該幅土地總成本高達33億5千萬港元，是至1989年爲止香港最高的土地售價。

該幅土地融資的每日利息便高達918,000港元。因此，建築師、顧問公司和發展商屬下的承建商均倍受壓力，他們必須使大廈可以盡快啟用，但同時不會降低發展商嚴格的質素標準。

工程內容

中環廣場原先的設計是配上玻璃幕牆的結構鋼綜合建築。設計師在檢討了鋼結構的建築成本和工程技術之後，決定轉爲採用鋼筋混凝土建築。此項改變極大的降低了建築成本，由16億港元降至10億港元。它還消除了發展商對大廈鋼支架不大美觀及採用鋼結構限制了設計靈活性等顧慮。必須指出，由於施工開始時大廈的詳細服務設施尚未最後確定，因此建築設計極需具備最大靈活性以應付各種改動。

設計師選擇採用鋼筋混凝土，使樓板面積由1,935平方米增加到2,215平方米。這樣做使大廈高度略爲降低，但能爲租戶提供所需要的大面積樓面。

採用鋼筋混凝土還使施工進度加快。平均每4.5日完成一層樓。

施工工程分三期進行(不包括地基和三層地庫)。第一期建至第27層，第二期建至第45層，而第三期包括餘下的辦公樓層、五個機房樓層和摩天大廳。此外，大廈頂部另有六層機房樓面(離地306米)，以及使中環廣場具有破紀錄高度的鋼桿。

與其周圍大廈比較，中環廣場顯得氣勢超羣。雖然大廈總樓面面積多達143,000平方米，但其三角形設計創造出一種苗條美觀的效果。

six additional plant floors (306m above ground level) and a steel mast that brings Central Plaza up to its record-breaking height.

Now that it is fully completed, Central Plaza dwarfs its neighbours. The overall effect projected by the triangular design is of a slimmer, more elegant building than its 143,000m^2 floor area might suggest.

Why PFA?

For such a tall building, the structural engineers felt it inappropriate to employ the 30 or 40MPa concrete used to construct most Hong Kong buildings. They wanted a high-strength concrete to reduce the size of the vertical members in the structure. Approval was therefore obtained from the Buildings Ordinance Office to utilise a high-strength concrete with a design strength of 60MPa. This was the first time such approval had been given for a private sector development in Hong Kong.

Considerable research took place regarding locally available materials and mix design options. Trials were carried out, including mock-ups of the large 2.8m diameter circular columns and 1.5 square columns for typical floors, to check on the temperature effects associated with the heat of hydration of concrete. The mix design eventually adopted is shown in the accompanying table.

The large quantity of cement in a 60MPa concrete generates high heat of hydration, especially in large pours, and water cooling systems were introduced. PFA as a cement replacement up to the allowed maximum of 25% was used to reduce temperature still further. PFA had the added benefit of curbing shrinkage.

From floor 5 through 19, PFA concrete was placed without the need for a cooling system. This resulted in a considerable reduction in pour costs. Pouring was achieved using standard stationery concrete pumps and placing booms.

Whenever it was used, the PFA concrete performed either as expected or beyond expectations. Typical of the last point is the fact that the 28-day core samples exceeded the specified minimum design strength by a considerable margin.

In addition to the high strength and the lower heat of hydration resulting from the incorporation of PFA in the concrete mix, other benefits of note included: improved workability and pumpability, reduced thermal cracking, good chemical resistance, and worth-while cost savings. At the end of the project, the structural engineering consultants stated that PFA should be regarded in Hong Kong as another important constituent of a good structural concrete mix, just as it is in other parts of the world.

Supply

The 8700m^3 of PFA concrete used at Central Plaza was batched by Pioneer Concrete (Hong Kong) Ltd. Pioneer sourced the PFA from Lamsonite Company Ltd.

A fast construction rate was achieved using reinforced concrete. *利用鋼筋混凝土使工程進度加快。*

煤灰的功用

結構工程師認為，對於這樣高的大廈，如果採用大多數香港建築物所用的30至40MPa混凝土是不適當的。他們需要高强度混凝土，以便能縮小垂直結構混凝土件的尺寸。香港政府建築物條例執行處批准他們採用高强度60MPa混凝土。這是香港私人樓宇發展項目首次獲得批准使用這種混凝土。

隨後對本地可供的材料和伴合設計進行了大量的研究及許多試驗， 包括製作具代表性的2.8米直徑的大圓柱及1.5米正方柱實物模型以檢查溫度效應。附表列出最終採用的伴合設計。

由於60MPa混凝土中的水泥大量連續澆灌時會產生高水化熱，所以設計了水冷卻系統，以便控制混凝土溫度，另外亦使用煤灰代替混凝土中約25%的水泥成份，以進一步控制溫度。煤灰的另一個優點是減少了混凝土的收縮性。

The completed Central Plaza. At 374m it is the world's tallest reinforced concrete building.
眺望完成後的中環廣場，這座374米高的建築物是現時世界上最高的鋼筋混凝土大廈。

Quality assurance and quality control posed no special problems as site workers were properly briefed and supervised on the characteristics of both PFA and high-strength concrete.

All parties involved with the Central Plaza project commented that they would not hesitate to use PFA concrete in future whenever project specifications permitted.

Conclusion

PFA has been used successfully for many years worldwide as a constituent of structural concrete due to technical and economic benefits its specific physical and chemical properties provide endusers.

Central Plaza is one of an increasing number of prestigeous Hong Kong building projects on which PFA structural concrete has been accepted as a wise engineering choice for technical reasons. Other such projects include Cityplaza 3 and 4, the Tsim Sha Tsui Cultural Centre, and the Government Offices in Wanchai.

Acknowledgements

Developers:
Sun Hung Kai Properties Ltd
Sino Land Co Ltd
Ryoden Property Development Co Ltd
Consultant (Structural):
Ove Arup & Partners
Architect:
Ng Chun Man & Associates
Contractor:
Manloze Construction Co Ltd
Concrete Supplier:
Pioneer Concrete (Hong Kong) Ltd
PFA Supplier:
Lamsonite Company Limited

從第5層到第19層，澆灌煤灰混凝土時可以不用冷卻系統。結果顯著地降低了澆灌成本。採用標準固定式混凝土泵和澆灌吊桿便可進行澆灌。

煤灰混凝土無論用作各種混凝土件，其性能均能達到或超越預期效果。這方面典型的例子是28日力度試驗大大超過規定的最低設計强度。

在混凝土混合料中採用煤灰，除了能提高强度和降低水化熱之外，值得指出的其他優點還包括：改善拌和性和泵送性，減少熱裂、有良好抗腐蝕性以及能顯著降低成本，結構工程顧問指出，有如在世界其他地方一樣，香港應將煤灰視作優良結構混凝土混合料的一種重要成份。

供料

中環廣場使用的8,700立方米煤灰混凝土由派安混凝土(香港)有限公司現拌，其中使用的煤灰由隆順有限公司供應。

由於向工地工人適當解釋了煤灰和高强度混凝土的特性並予以監督，品質保證和品質控制均沒有特別困難。

中環廣場工程之有關各方均指出，在未來的工程規範容許情況下，他們均會毫不遲疑地採用煤灰混凝土。

結論

多年來，煤灰已成功地應用於全世界各地的結構混凝土及其他土木工程中。煤灰在商業上的成功應用，是由於其特殊的化學和物理性能能爲用戶提供利益。

香港越來越多重要建築工程鑒於技術原因而在結構混凝土中採用煤灰，中環廣場是此種明智選擇的例證。其他重要工程包括太古城中心第3和第4座、尖沙咀文化中心以及灣仔的政府合署。

鳴謝

發展商：
新鴻基地產發展有限公司
信和地產投資有限公司
菱電地產發展有限公司
顧問(結構)：
Ove Arup & Partners
建築師：
Ng Chun Man & Associates
承建商：
Manloze Construction Co Ltd
混凝土供應商：
派安混凝土(香港)有限公司
煤灰供應商：
隆順有限公司

China Light & Power Co., Ltd.
中華電力有限公司 *Ash Marketing*

6/F., Sham Shui Po Centre, 215 Fuk Wah Street, Sham Shui Po, Kowloon, Hong Kong. Tel.: (852) 360 6215 Facsimile: (852) 360 6109

Annex D

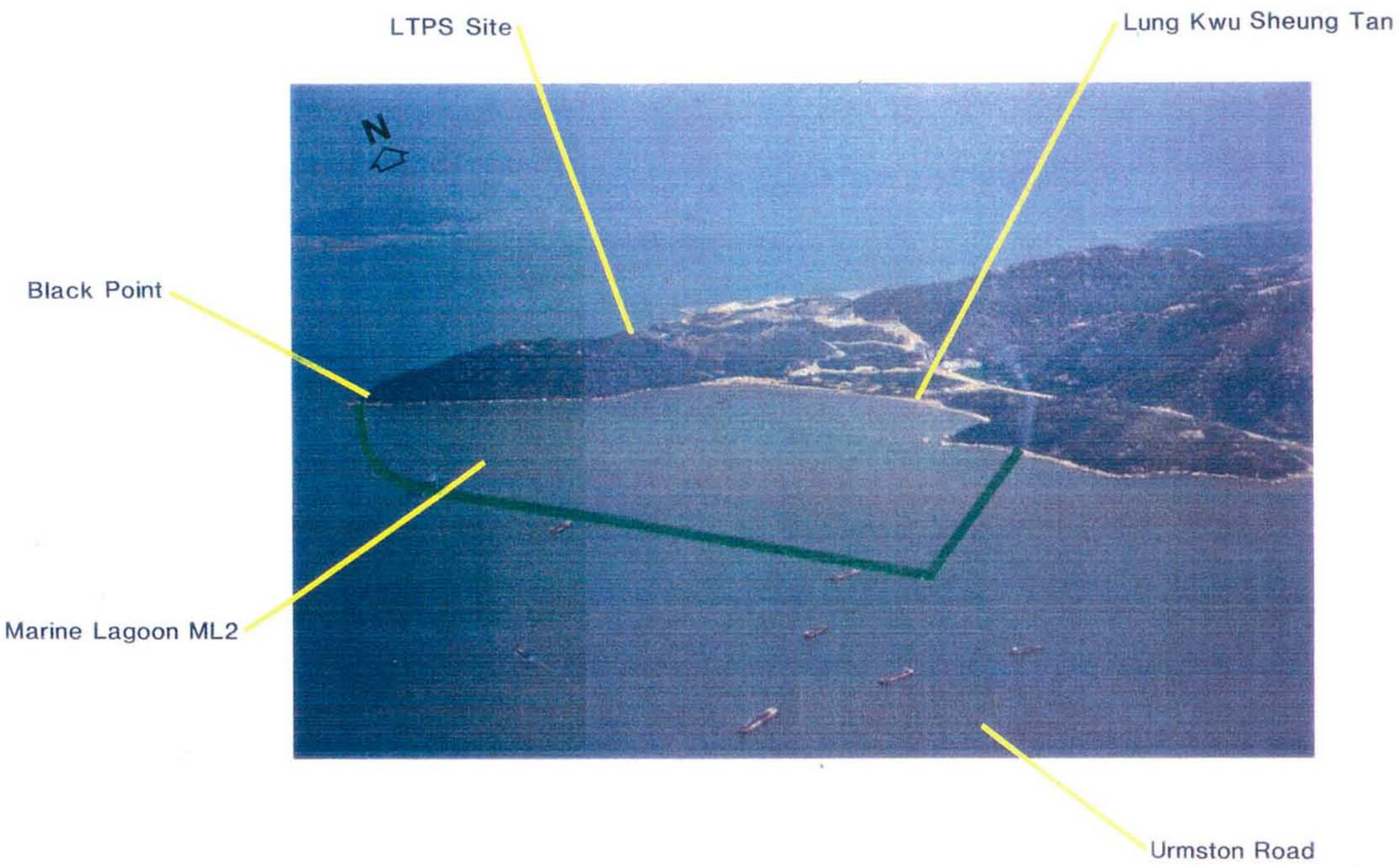
Aerial Photographs of Potential Disposal Facilities

Proposed Marine Lagoon ML1

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM



Proposed Marine Lagoon ML2

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

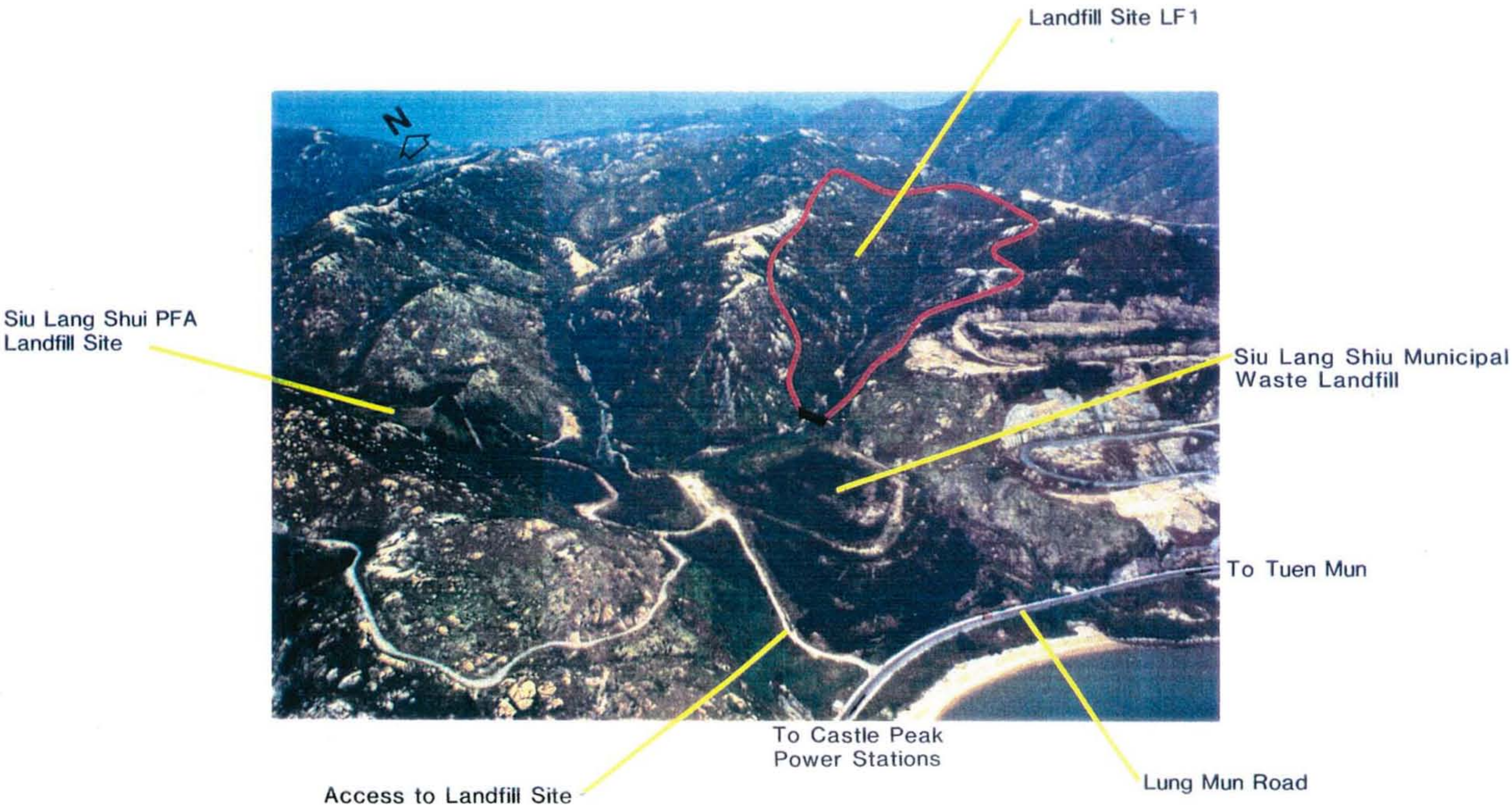
ERM

Proposed Marine Lagoon ML3 & ML4

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

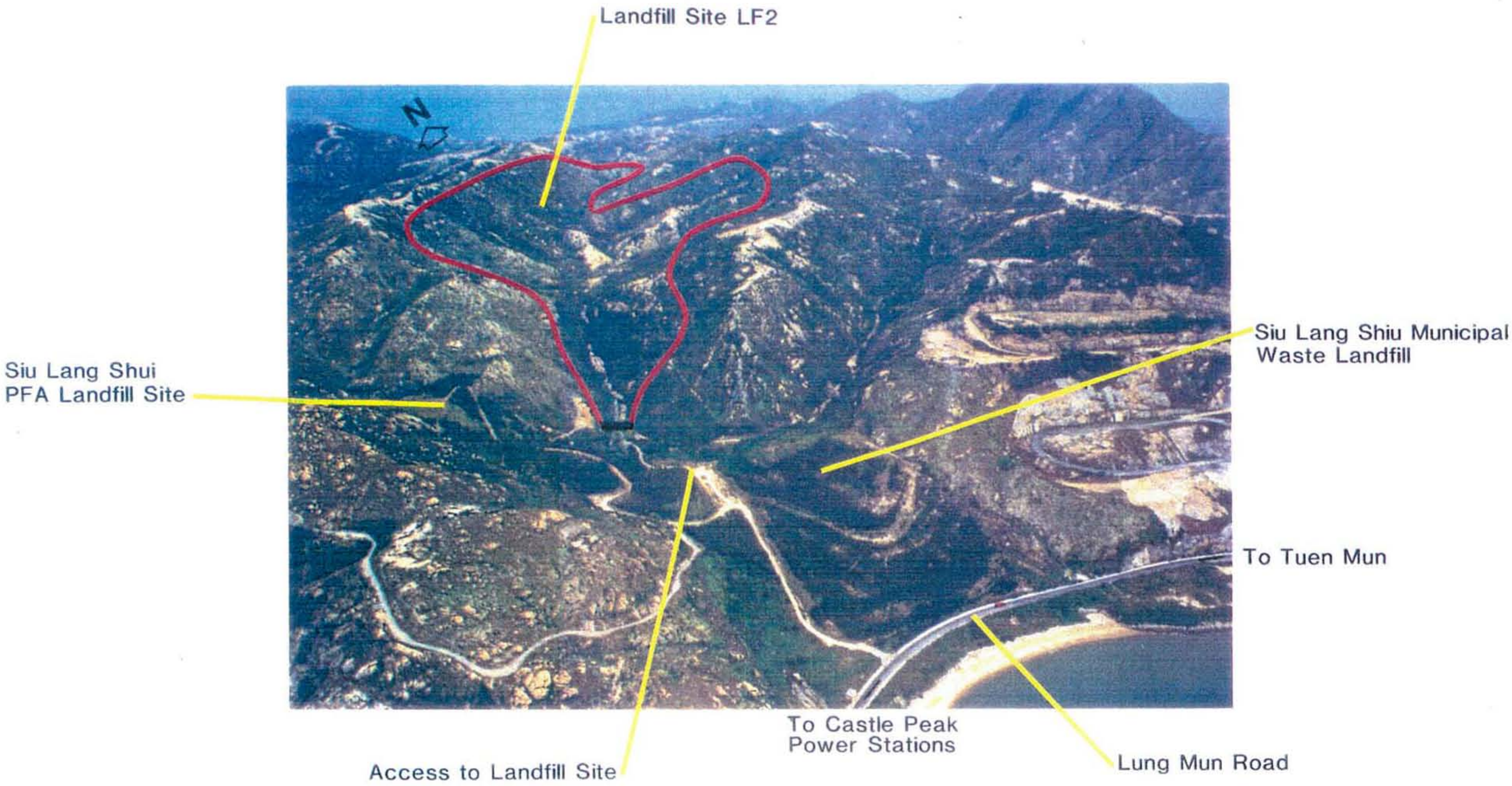


Proposed Landfill Site LF1

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM



Proposed Landfill Site LF2

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

Proposed Landfill Site LF4

ERM Hong Kong

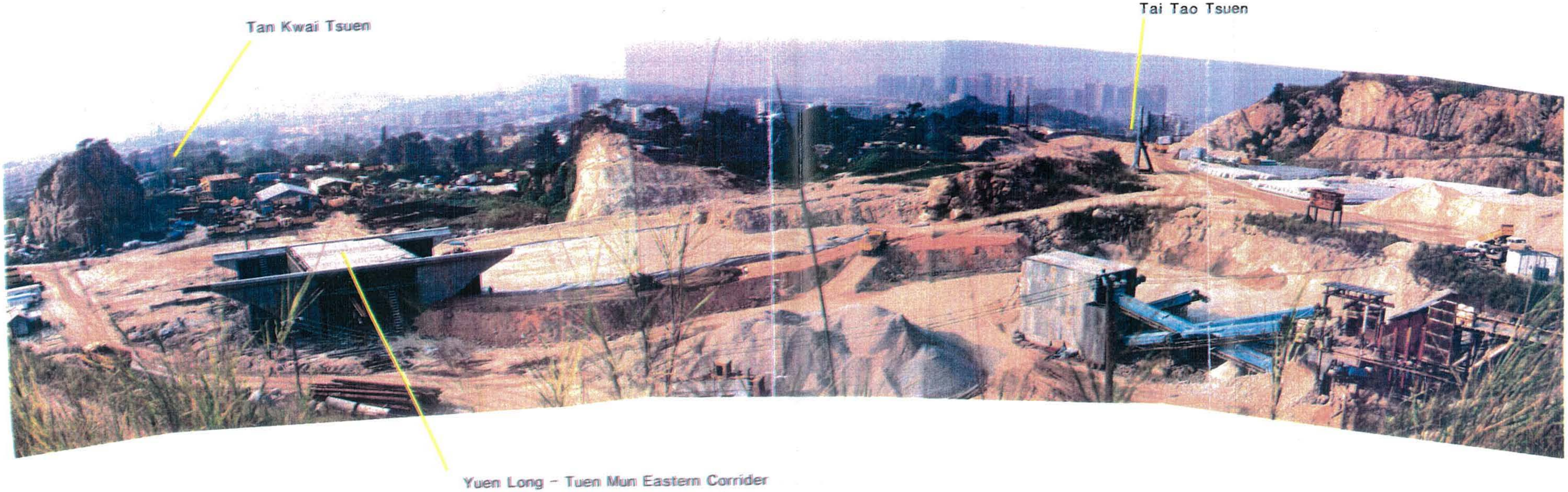
10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

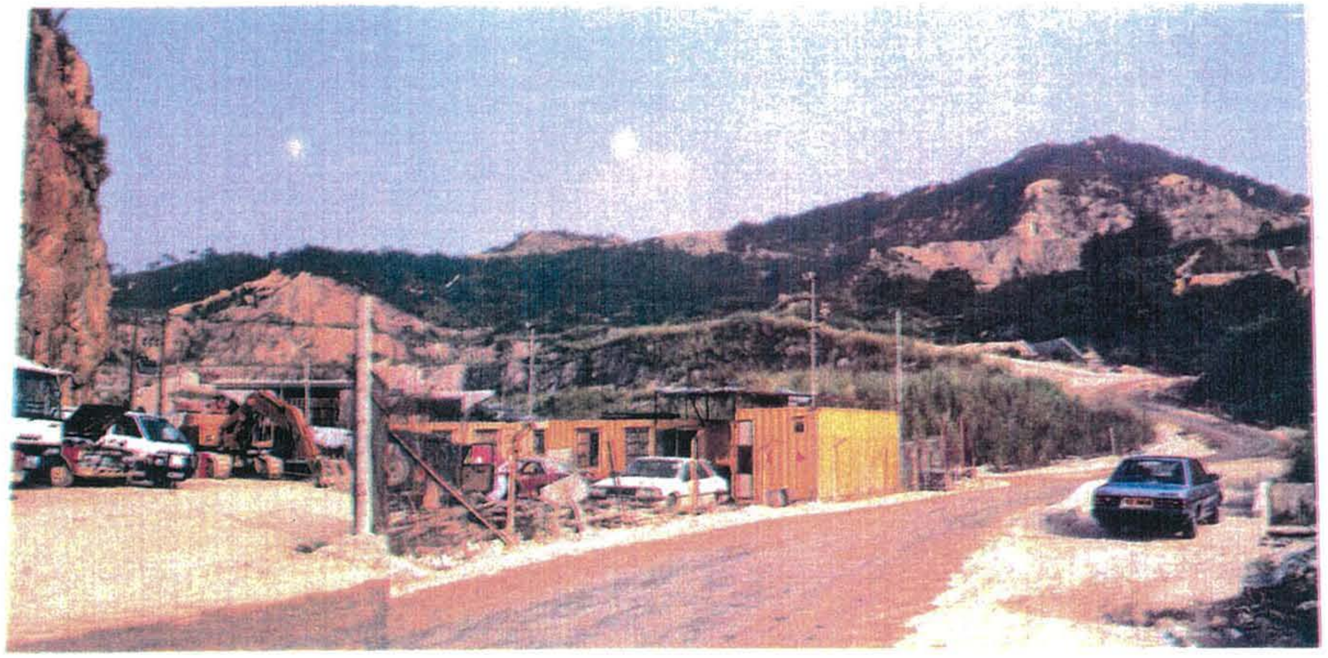
ERM

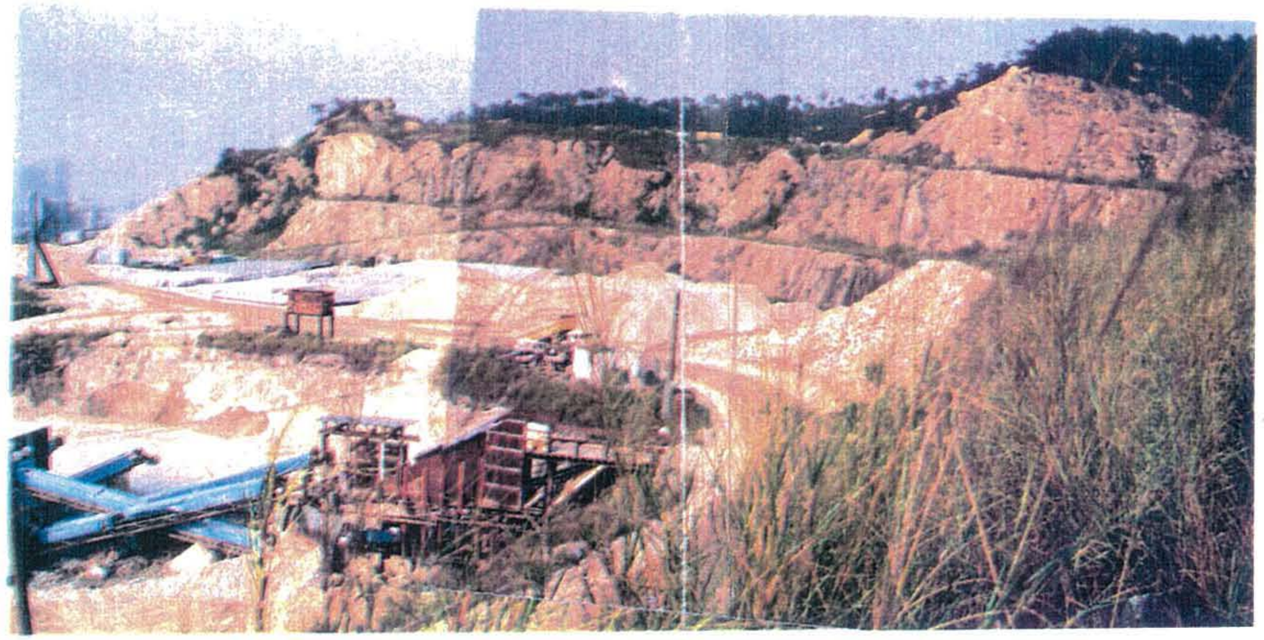
Photographs of Quarry Q1

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong







Photographs of Quarry Q2

ERM Hong Kong

10-11th Floor
Hecny Tower
9 Chatham Road
Tsimshatsui, Kowloon
Hong Kong

ERM

RESPONSE TO GOVERNMENT COMMENTS

Annex E

Response to Comments on EIA for LTPS at Black Point Solid By-products Key Issue Report

Response to Comments
on EIA for the LTPS at Black Point
Solid By-Products Key Issue Report

No.	Department	Reference	Comments	Consultant's Response
1	PELB		The Administration's decision on the long term disposal strategy for PFA is to use the material as reclamation fill in projects where this is considered by the FMC to be feasible. We understand that CED have been liaising with the power companies, including CLP, to make PFA available in the future for fill purposes. Implementation of this strategy would hopefully tackle the PFA disposal problem. The need to identify landfill sites will be alleviated to a considerable extent. Unless there are other considerations, we do not think the landfill options within the Castle Peak Firing Range need to be further pursued.	Notwithstanding the acceptance of the use of PFA for fill, this is dependent upon numerous planning and procedural permits and discussions. The remarks concerning PFA utilisation are noted and supported. However, it is essential that CLP have contingency plans to dispose of LTPS by-products that are not utilised. The SKIR sets out various dates by which planning for disposal facilities would need to commence under various scenarios. The use of landfill sites is given as the fallback position and the provisional reservation of a site seems prudent to safeguard the Territory from a difficult disposal problem in the worst case.
2	EAPG	General	a) As commented below by WMPG, this report serves more as a framework for further development of the by-products management strategy. CLP/ERL should further investigate the options to establish their feasibility, cost-effectiveness and environmental merits, and firm up a by-product management strategy for EPD's consideration.	As the comment acknowledges, the KIA Report does establish CLP's Byproduct management strategy. The specifics of its implementation depend upon the largesse of Government. Further work on the fundamentals of the strategy at this time would not further the specifics of the strategy to be implemented.
			b) Since the use of PFA as fill material above and below seawater has now been accepted by the government, the consultants should take this into account in their formulation of the PFA management strategy.	In establishing the strategy for beneficial use, the use of PFA both above below water line has already been taken into account (see p.85).

No.	Department	Reference	Comments	Consultant's Response
			c) We have strong reservation on the proposal to discharge the FGD gypsum via cooling water. The Water Quality KIR and this report have failed to establish that the seawater disposal option is environmentally acceptable.	The proposal to dissolve gypsum is made with a view to reducing the disbenefits associated with disposal of the solid products. The water KIR indicates that the dissolution of gypsum will not cause significant environmental impacts with regard to appropriate criteria.
3	WMPG	General	a) It is noted that utilisation and disposal options (with/without ranking) are proposed as the long term management strategy for all by-products arising from the LTPS (PFA, FBA, FGD gypsum and Wastewater Treatment Sludge). However, the feasibility of most of the utilisation options are subject to further investigation and trial, and the feasibility of all disposal options are subject to resolution of constraints. For example, seawater FGD process is dependent on proving the technical and commercial feasibility of the technology and on the impact to the marine environment (P.195), and the disposal options for PFA is dependent on the availability of sites (P.123). As a framework for the further development of the by-products management strategy, the consultants' recommendations are considered acceptable in principle *provided all our views are taken into account*. But CLP/ERL should further investigate each option in details and recommend the option(s) to be adopted, followed by recommendation of a firm by-products management strategy for EPD's consideration.	Prior to embarking upon detailed planning studies and expensive engineering exercises, it is necessary to ascertain preliminary feasibility and important to confirm the environmental viability of the processes concerned. Options, such as seawater scrubbing and gypsum dissolution are probably feasible, but require Government's approval of the concepts before detailed investigations are instigated to prove feasibility. The KIR therefore aims to address the macro and worst case environmental conditions to facilitate Government's decision making process. See also response to comment 2 above.

No.	Department	Reference	Comments	Consultant's Response
			b) It is also noted that the feasibility of the options are dependent on the firing scenario and the FGD process. CLP/ERL should therefore advise us: i) on the intended firing scenario and FGD process; ii) what are their proposals and the corresponding programme for assessing the feasibility of the utilisation and disposal options recommended in this SKIA. Please note that planning for the disposal facilities may be very tight. For example, the detailed planning for the disposal facility for FGD gypsum must commence in 1993 if scenario I is adopted (re: Para 1, P.168).	The feasibility of the options are not dependent upon the firing scenario, but upon environmental acceptability and engineering and economic practicability. The options recommended in the SKIR are considered to be feasible, as discussed in the report.
			c) In March 1992, a LDPC Paper on "Disposal of PFA - Use as General Fill in Construction" was endorsed. This paper empowers FMC to require Government Departments in future to use PFA as reclamation fill in projects where this is considered by the FMC to be feasible. The LDPC paper also states that apart from areas which are particularly environmentally sensitive, the use of "leached" PFA from lagoon as general reclamation fill both above and below water is considered acceptable. Therefore, the consultants should take into account the recommendation of this LDPC Paper and re-assess the utilisation of PFA and the management strategy.	Noted, see response 2, (b) above. We would appreciate a copy of the LDPC paper and would reaffirm the conclusion that the use of lagooned PFA conditioned PFA and FBA are suitable reclamation materials.

No.	Department	Reference	Comments	Consultant's Response
			d) The preferred option for FGD gypsum is beneficial use. Export to other country is considered better than disposal in Hong Kong. The proposal of discharging dissolved gypsum via cooling water is certainly unacceptable to us.	We fully concur with the preference for beneficial use. Export to other countries *may* be economically feasible, but cannot be considered wholly secure. Disposal or use within HK therefore must be addressed. We would appreciate clarification as to why the discharge of dissolved gypsum is unacceptable to you, particularly in view of the findings of the Water Quality KIA.
			e) It was proposed by CLP and the consultants that seawater FGD process would be addressed in the SKIA (re: ERL's letter dated 20.6.91). Please explain why this issue is now not included. Has this process discarded for further consideration?	The Seawater process does not give rise to significant volumes of solid waste and it was not therefore, principal topic for the Solid Byproduct KIA. The Process and its impacts have been considered both in the SKIR (see for example Section 5.3.4) and in the WQKIR as appropriate.
4		Utilisation-(a) (P.iv, Executive Summary)	Can the off-specification gypsum be utilised beneficially in other area?	This may prove to be possible, dependent upon the quality of the material involved. However it cannot be relied upon as a management strategy.
5		Fig 2.2(g), (h), (k) & (l) (P.25-26)	"Annual Production" and "Cumulative Production" should read "Annual Consumption" and Cumulative Consumption".	Noted.
6		S.3.2.9 (para 3, P.78)	The current status on use of PFA stated is out-dated. Please note Government's view on the use of PFA as fill expressed in the LDPC Paper on "Disposal of PFA" (please see our general comments).	Noted. See responses 2(b) & 3(c).
7		S3.3.5(b) (P.108)	Please note that the redundant borrow pit at Urmston Road has been assigned for disposal of uncontaminated mud.	Noted, this does not affect the conclusions of this section.

No.	Department	Reference	Comments	Consultant's Response
8		S3.3.5(d) (P.109)	Marine disposal of PFA within or outside Hong Kong waters is not recommended.	Noted. The SKIR concludes dumping inside HK waters is not a viable option. Dumping outside HK waters is only considered as a last resort.
9		S3.4.4 (P.121-123)	As commented earlier, the consultants should reassess the PFA utilisation options and management strategy in the light of the change in attitude towards the use of PFA as reclamation fill below seawater table.	Noted, see responses 2(b) & 3(c).
10		S4.3.1(a) (P.133)	We are not aware of any suggestion from CLP to stockpile excess arisings of FBA at an above water level area to the south of the west lagoon at Tsing Tsui. This will only be considered when detailed information is provided.	The suggestion was made to the Consultants by CLP for consideration. The SKIA concluded that such an option would be perfectly feasible. No official approach has been made by CLP to government to date as far as we know.
11		S4.3.1(a) (ii) (P.134)	If these options are to be pursued, the requirement for separate storage for PFA and FBA should be taken into account.	Noted.
12		S4.4.4(a) (P.139)	Presumably, "Section 3.4.2" in Line 1 read as "Section 4.4.2".	Noted.
13		S5.2.6 (P.148-149)	CLP should ensure that they will have a secure disposal route for any by-product arising. For gypsum, the preferred option is beneficial use. Export to other country is therefore considered better than disposal in Hong Kong. Any back-up facilities should only be considered as a contingency plan to cater for a short period disruption of the export arrangement. Disposal at Hong Kong is not recommended.	As stated in 3(d) above, beneficial use is acknowledged to be preferable to disposal. Provision of disposal facilities, however, requires early development of a disposal site which can cater for a contingency at short notice. The provision of such a site would appear to negate the recommendation that disposal should not take place within Hong Kong.
14		S5.3.3(c) (v) (P.163)	Please see our comments on S5.2.6.	See response above.

No.	Department	Reference	Comments	Consultant's Response
15		S6.3.3 (Para 1, P.175)	In view of the large quantity of WTS, it is not recommended to dispose WTS at landfill.	Noted. The quantities predicted are again the absolute worst-case we can envisage and the report proposes means by which it may be possible to utilize the waste. However, disposal at landfill may be the only practical option. See also response 35.
16		Chapter 7 (P.181-201)	Please see our general comments.	Please see our responses to those comments.
17		Table 7.1(a) (P.184)	There are two number of "Rank 4" under the item "economic issue". Please clarify.	These are ranked 4=. Note that there is no option ranked 5.
18	SCG	General	The study should address the methods and environmental impacts of delivering the solid by-products to the proposed disposal facilities when evaluating the options of marine lagoons, landfills and quarries.	These issues have been considered in general terms. It is not appropriate to conduct detailed EIAs of each disposal option at this stage, since constraints would vary according to the specific site under consideration. However transportation is unlikely to be an overriding consideration to the viability of each option and its consideration has been taken into account in the selection of sites and ranking of the options.
19		S3.3.2(i)	Regarding the extension of Tsang Tsui Lagoon, the Consultants should consider the possible environmental impacts if they propose to deliver the PFA (even if it is conditioned) by trucks. The amount of PFA to be filled up from 30 mPD to 40 mPG is 5,000,000 cu.m. approximately. Trucking of this tremendous amount of PFA to the lagoon may not be a favourable solution.	Trucking amounts of PFA that cannot be transported by pipeline to Tsang Tsui from LTPS or CPPS is considered a preferable option to trucking to other sites in view of the short distances and relatively low density of sensitive receivers involved. The alternative sites could involve trucking over longer distances past more sensitive receivers and hence may be less favourable that disposal at Tsang Tsui. The issue would be resolved during the EIA of the expanded lagoons after agreement, in principal, for expansion is reached.

No.	Department	Reference	Comments	Consultant's Response
20	APG/ACG	General	Although we may not have strong objection to the use of heavy fuel oil having high sulphur content, it is prudent to point out that FGD and other BPM must be adopted to cut down the high air emissions, and that its acceptability is subject to an EIA study.	Noted. The Air Quality Key Issue Study addresses, in detail, the air quality impacts associated with oil-firing with BPM control measures. The SKIR has sought to assess the impacts of the air control measures to the environment from solid by-products.
21		S3.2.2(c), (P.59), S7.2.2(a) (P.188), PFA Management (Page iii, Executive Summary	The disposal of PFA by means of utilisation of PFA in cement industry is always encouraged by EPD. However, it would not be acceptable if such disposal is achieved at the expense of environmental pollution in other form. We therefore do not think that the utilisation of PFA by China Cement company would merit a lowering of standards for the emissions, say, air pollution emissions, from the cement plant.	Noted. The report does not cover emission standards at China Cement, but merely seeks to give an overview to the problem in terms of the overall environmental benefits of PFA utilisation. Similarly, the SKIR is seeking to establish that the institution of air pollution controls would not result in unacceptable environmental pollution in other forms.
22		S3.2.3(d)	For the consultants' information, it is our intention to include the concrete batching in the list of SP as part of the amendment to the APCO.	Noted and agreed.
23		S3.2.4(c)	Dust and energy problems caused by PFA lightweight aggregate manufacturing are the main concerns to us. CLP/ERL should address these issues properly if they wish to pursue this option.	Noted, more detailed study would be enacted if the option were pursued, although as we pointed out in the report the use of lightweight aggregate is not presently permitted in Hong Kong.
24		S3.2.6(b)	Though we believe that the use of PFA as a landfill material will not cause unacceptable dust nuisance if proper control measures are implemented, the suggested list of mitigation measures is by no means exhaustive. Additional measures may be required depending on the specific means of transporting and handling the PFA inside and outside the landfill.	Noted, these would need to be the subject of further study if the option were pursued. As you note dust nuisance is unlikely to make the option infeasible.

No.	Department	Reference	Comments	Consultant's Response
25		Table 3.4(b), (c) & (d)	Option Q1 and Q2 will imply heavier road traffic of trucks through populated areas, which may result in dust nuisance due to heavy truck traffic and possible incidents of PFA spillage. The ranking of Q1 and Q2 should be reviewed in this context.	Q1 and Q2 are already ranked bottom of all options reviewed and would be a last resort in considering on-land disposal facilities for PFA.
26		S5.3.3(b)(iv)	Presumably, "section 6.3.3(a)" in Line 2 read as "section 3.3.3(a)".	Noted.
27	NPG	General	a) As the site for the power station is quite remote from noise sensation receivers, noise breakout from the power station is not of major concern.	Noted.
			b) Regarding the disposal of PFA, assuming the ash lagoons at Tsang Tsui, ML 1, 2, 3, 4, are to be filled by open-bottom barges, noise disturbance to nearby NSR is not envisaged.	Noted.
			c) For the landfill sites, LF1, LF2 are away from NSR and should not cause any noise problem. While LF4, Q1 & Q2's locations are acceptable from noise point of view, the assess roads to these sites are of concern as the dump trucks will pass through some highly populated villages. Independent noise assessment about the impacts on these villages should be carried out.	Noted, detailed study would be necessary if these options are pursued.

No.	Department	Reference	Comments	Consultant's Response
28	LCG	General	a) The basic concept of allowing gypsum to dissolve in seawater needs to be examined more carefully, both from a water quality and a liquid effluent control point of view. The two proposals stated in the report are: i) limestone/gypsum FGD process - redissolution of gypsum in seawater and discharge to sea via the cooling water outfall; and ii) seawater FGD process - the product gypsum remains as a solution/suspension and is discharged to sea. In both proposals, the consultants have not addressed the impact of such a large load of gypsum on the marine environment, nor has it been established in the WKIR that it is acceptable.	Impacts to the marine environment of dissolved gypsum are the subject of sections of the WQKIR. Please see 'response to comments' to your comments on that report.
			b) As regards the solubility of gypsum (S5.3.3(a)(i), para 5, P.155), it is stated that gypsum is sparingly soluble, having a maximum solubility of about 2 g/l at 25°C. Is this referring to solubility of gypsum in fresh water or seawater? Gypsum is not very soluble in water and any solution/suspension of gypsum in cooling water would have high levels of suspended solids (SS).	The figure refers to freshwater. The manufacturers of the seawater systems claim dissolution of gypsum is essentially complete before discharge to the environment. This would in any case, need to be guaranteed by any vendor.
			c) It should be noted that effluent discharge standards would be given by the Authority on different waste streams of the LTPS, including the cooling water discharge. In this respect, the discharge of gypsum in seawater may not meet certain parameters such as SS, COD etc.	Noted - see responses to WQKIR.

No.	Department	Reference	Comments	Consultant's Response
			d) Whenever landfilling is considered to be a disposal option for PFA, FBA and gypsum etc., the leachate problems should be fully addressed. Similarly, when lagooning is proposed, decantrate aspects should be adequately considered.	Noted, leachate would be the subject of later study were particular landfill options pursued. Decantrate return has been addressed in the WQKIR.
			e) Although government actions have been proposed for some of the utilisation and disposal options identified, the onus of finding and choosing the best option or more likely, a combination of options, should be on the proponent and not on the government.	The SKIR proposes what are considered to be the best options. The provision of the administrative measures for their adoption/implementation however, lies within Government.
29		S3.2.9(b)(ii), Leachate (Para 1, P.83) and S3.3.3(a) (iv), Water quality (P.101)	It is not true to say that the TM specifically excludes runoff from landfills. Any contaminated runoff may have to be treated in accordance with the Authority's requirements.	Runoff would be treated in accordance with the Authority's requirements if necessary (see also comment 33(a)).
30		S3.3.3 (Para 3, P.99)	The consultants may wish to revise this paragraph in light of the recent development concerning extraction of fill material from the Castle Peak Firing Range.	Noted, we would appreciate specific information relating to these developments.
31		S5.1 (Para 4, P.143 and Para 1, P.144)	As the gypsum produced from either the limestone/gypsum FGD system or the seawater FGD system would contain other contaminants (eg toxic metals), can the consultants provide further information on the characteristics of gypsum produced after the scrubbing process? This would be useful when assessing the pollutant loading to the environment.	The seawater FGD system does not produce solid gypsum. Please refer to Table 2.5(c), p47 for gypsum analyses. (Note this has been amended due to typo's and is attached in corrected form)

No.	Department	Reference	Comments	Consultant's Response
32		S5.3.4(a), Discharge of dissolved toxic metals (P.164)	As mentioned in our comments on S5.1 the heavy metals trapped in the gypsum or dissolved in seawater needs to be assessed. In the Water Quality KIA (Para 1, P.33), the predicted total heavy metal discharge from the worst case scenario is almost 30,000 kg/yr. What is the percentage contributed by the limestone/gypsum FGD system and the seawater FGD system respectively?	Information regarding the individual contributions to the total metal discharge, please see Annex 1 of the Water Quality KIA Response to Comments Document.
33		S6.1 (Para 2, P.171)	In seawater FGD, as the contaminants (including heavy metals) are withdrawn with the 'dissolved' gypsum, the total pollution loads would remain the same, regardless of whether the contaminants are entrained in seawater or in the purge water.	This is basically correct, however it should be noted that the seawater scrubbing system does not produce a purge stream.
34		S6.1, Para 2, P.172 & S7.5.1 Para 3, P.199	It is said that by requiring special handling via separation of the inert solids and toxic contaminants in effluent treatment, sludge reduction can be achieved with only about 20% of the sludge containing toxic contaminants at raised levels. Has this process been practised before elsewhere and how dependent is the expected production of 80% 'inert' sludge and 20% 'polluted' sludge on other varying factors?	The process referred to entails desaturation of the purge stream prior to raising the pH to levels at which metal precipitation will occur. It is understood from plant manufacturers that this process is used in Europe.
35		S6.3.3 Para 1, P.175	It should be noted that dewatered sludge to even 25% dry solids content may not be acceptable at the new strategic landfills.	Noted. The SENT landfill specification permits dewatered sludges with a water content not exceeding 80% by weight under Type 1.
36	WPG	General	a) As the consultants suggested a full utilisation of FBA by the construction industry, we have no more comment on its management plan.	Noted. Full utilisation is dependant on take up by the construction industry.
			b) We have strong reservation on the seawater disposal option for FGD gypsum and oppose the priority list for gypsum management set in the report - the consultants ranked the seawater disposal option above all other options.	The ranking for the Seawater system is conditional on the system being shown to be technically feasible and the environmentally acceptable in the WQKIR. See also responses 2(c) and 3(d) above.

No.	Department	Reference	Comments	Consultant's Response
			c) The consultants have proposed a number of options to recycle/utilise PFA in the construction industry. However, they tend to shift the responsibility to the government. CLP should realise that setting up of pilot plant to implement these recycle process would attract industrial interest and make the recycle process commercially acceptable.	Many of the proposals require the approval, in principle, of Government before further study/action can be undertaken.
37		S2.1.1(b)(i) & S5.1	a) As stated in the Water Quality KIR, high metal content is found in the gypsum. If dissolved in water, this would have serious impacts to the surrounding waters.	See responses to comments on the WQKIR and 2(c) and 3(d) above.
			b) We would not support the proposal to use recycle water, especially seawater, if it leads to the disposal of gypsum via cooling water.	As above.

No.	Department	Reference	Comments	Consultant's Response
38		S3.2.6	The relative low permeability of PFA could affect the effectiveness of the leachate collection system in landfill. The consultants should provide solutions to overcome this problem.	If PFA is used as an interleaving material, leachate and gas movement may be restricted, causing perched leachate tables and increasing the potential for lateral migration. However, the Specifications for WENT and SENT favours the use of gas collection wells which are built up from the site base, and constructed from granular material. For collection efficiency and long term structural stability, such stone columns are likely to be of large diameter and are likely to provide an effective drainage path for leachates. As such, subject to review of contractors design proposals, the use of PFA may not effect the effectiveness of leachate drainage within the sites. Another means of overcoming concerns of leachate drainage would involve restricting the areas of application of the PFA; if a 'down slope' or 'up slope' means of waste deposition is proposed, PFA cover material on the slopes *only* would significantly reduce the likelihood of a continuous horizontal 'blanket' or barrier being created. The actual use of PFA would be subject of trials at a landfill if the operator of the facility so wished.
39		S3.2.9(b)(ii), S3.3.3(a)(iv)	We usually require extensive leachate collection system for non-soil material used in reclamation. The leachate should be collected before discharged and it would be subjected to the TM requirements. We also require proper collection system to receive and treatment system to deal with the contaminated surface runoff before it is discharged to other nearby waters.	Please refer to comment 3(c) and the Consultants response.

No.	Department	Reference	Comments	Consultant's Response
40		S3.2.9(b)(ii)	High turbidity/SS generated by bottom dumping of PFA is a result of the relatively fine particle size of PFA. We doubt that good design of seawall or good site management practices would help in preventing high turbidity or siltation at nearby waters.	Noted. However measures may be available to contain and minimise silation. Such as a screen or curtain at the entrance to reclamation that could be raised and lowered once a boat passed through. Such systems may also help with siltation/turbidity with conventional reclamation techniques.
41		S3.2.9(b)(iii)	The collection system (re: last paragraph) should be connected to proper treatment facilities before discharge.	Noted. Treatment facilities would be included if necessary.
42		S3.3.3(a)(iv)	a) Siltation problem caused by PFA lagoons to the adjacent area need to be addressed. Although it may not be significant if the lagoons are specially designed, using PFA as reclamation fill in partially enclosed reclamation sites may give rise to severe increase in turbidity in the surrounding marine areas.	We assume you refer to S3.3.2(a)(iv). Tsang Tsui lagoons were specially designed and no significant impacts would be expected with similar lagoons. The issues of partially enclosed reclamation sites are identified in Section 3.2.9(b) and 3.3.2(b)(iv).
			b) The concentration of some toxic metals inside the lagoons does not seem to be high. However, one should notice that in the leachate tests with both seawater and deionized water using lagooned PFA, concentration of leached heavy metals are much higher.	Noted. Aspinwalls report details the test procedures adopted and clearly state the methods used produce extreme concentrations which are only applicable to the first bed volumes not the overall leachate. Despite this the results are broadly in line with TM metals levels and give no cause for concern. PFA in CLP's lagoons has already undergone initial leaching when it is pumped from Castle Peak as a seawater slurry.
			c) There is no mention of environmental impacts due to increase in heavy metals leachate associated with the extension of lagoons. Possibility of escape of silt due to run-off of PFA is not mentioned too.	Increases in 'heavy metals leachate' due to expansion of Tsang Tsui are not considered significant since site area would remain unchanged and PFA previously placed is washed by that placed above it, dramatically reducing the metals leached. The extension to the lagoons would need to be designed to avoid silt runoff. Both the above topics would form part of any detailed study were the proposals to proceed.

No.	Department	Reference	Comments	Consultant's Response
			d) We presume that the "appropriate site management" (re: Line 12, Para 3) includes the proper management of the interception of contaminated surface runoff and slope stability problems.	Noted. These would be the subject of detailed planning studies.
43		S3.3.3(a)(iv)	a) Although the TM does not cover surface runoff, the runoff should be collected and properly treated before discharge since it will be contaminated by the high metal contents of PFA.	Please refer to comment 29 from LPG and the consultants response.
			b) Groundwater contamination and site specific issues related to diversion of streams, should also be addressed.	Noted. See response 32(d) above.
44		S3.3.3(b)(iv)	Should LF4 be further reconsidered, stringent mitigation measures, should be imposed to protect streams, groundwater and nearby coastal waters.	Noted. The SKIR recommends study of these key issues if the proposal were pursued.
45		S3.3.4(e)	The potential danger of groundwater contamination should be addressed. The underground limestone cavity problem in that area would increase the potential threat of groundwater contamination.	Noted. Each of the disposal proposals would require detailed environmental studies as noted in the SKIR.
46		S4.2.5	The only advantage of FBA over PFA as reclamation fill is that it has a bigger particle size thus easier to settle and would not generate high turbidity in the nearby waters. However, the problem of leachate still exist.	Noted. FBAs greater particle size means less surface area is available for leaching in a given weight of material. Hence greater proportions of the metals are locked in a solid matrix. In addition, all FBA is removed by wet methods which results in readily soluble metals being pre-leached.
47		S5.1	We would like to see more discussion on Seawater FGD system but rather in the Water Quality KIR.	Noted.
48		S5.3.1(a)(ii)	We are strongly against the idea of dissolution of gypsum in cooling water. Our specific comments are clearly stated in our earlier comments on the Water Quality KIR.	Noted, but see earlier responses, particularly 2(c) and 3(d).

No.	Department	Reference	Comments	Consultant's Response
				See response 28(b) the WQKIR and response to comments.
50		S5.3.3(a)	a) In view of the high level of dissolved solids and high COD, we support the proposal of leachate collection and treatment before discharge. Moreover, we would like to point out that the transfer of toxic heavy metals from gypsum to surface/ground water may be significant. The cadmium, chromium and mercury contents of the expected LTPS FGD gypsum are quite high compared to both the Riedersbach FGD gypsum and the Voerde FGD gypsum, of which are intended for comparison. Toxic metal leachate from the LTPS FGD gypsum to surface/ground water should also be considered.	Noted. Cadmium & Chromium data were not available for Riedersbach or Voerde FGD gypsums. The expected levels for LTPS gypsum are highly dependent on the coal burnt, limestone reagent and process water (see also Annex 1 to the response to comments on the WQKIR). Those for Steinkhole FGD gypsum were derived from very pure coal and reagent, not available to CLP. Please also find attached corrected Table 2.5(c).
			b) No leachate control is mentioned in the consideration of Wet Stacking Method. In our opinion, leachate collection and treatment should be implemented like those recommended in the Dry Placement Method.	Noted.
51		S5.3.3(c)(iv)	Similar to our comments to PFA, potential groundwater contamination should be addressed.	Noted. See earlier responses.

No.	Department	Reference	Comments	Consultant's Response
52		S5.3.4(a)	a) Direct discharge of gypsum into the sea is completely unacceptable due to the following consideration: i) Although the tide current at the point of disposal may be strong, local saturation of gypsum may happen at some points where sea current slows down. Local precipitation of gypsum can occur, which will cause severe environmental impacts. ii) Insoluble constituents in the gypsum will severely raise the turbidity of the sea around the discharge area. iii) Discharging all the toxic metals in FGD gypsum into the sea not only cause substantial impacts to the marine biota in the area around the point of discharge but also to other remote environmentally sensitive regions.	In response to your general point, the consultants do not in general concur as set out in responses 2(c) and 3(d) i) The Seawater FGD system must be shown to be technically feasible prior to CLP pursuing the option. The supplier would have to demonstrate that all gypsum would indeed be dissolved at discharge. ii) Please refer to the WQKIR and response to comments thereon. iii) as ii) above
			b) We would like to have further details on the Bechtel and Flakt process, especially their assessments on marine environment. We have reservation on the possibility of implementing cost-effective measures to make the seawater FGD system environmentally acceptable.	Neither Flakt nor Bechtel have conducted studies relevant to the marine environment in Hong Kong.
53		Chapter 7	Dissolution of FGD gypsum in sea/stream must be prohibited.	See responses 2(c) & 3(d).

No.	Department	Reference	Comments	Consultant's Response
54	Civil Engineering Dept	on 18/9/92	With reference to my letter ref. (30) in this series of 13 August 1992, I wish to clarify the meaning of my comments in paragraph 4.1. The agreement which Government wishes to secure is for CLP to harvest the PFA from time to time and to load it onto barges and trucks supplied by Government contractors. Government's part of the agreement would be to use the PFA at a rate sufficient to ensure that there is always some spare capacity in CLP's existing temporary storage facilities.	Noted. Such an agreement would be very beneficial in utilisation PFA for CLPs Power Plant, whilst minimising the requirement for further disposal facilities.
55	Civil Engineering Dept	on 25/9/92	The Geotechnical Engineering Office has no further comments on the Consultants' response to our previous comments regarding the Solid By-Products Key Issue Report.	Noted.
56	District Lands Office, Tuen Mun	10 in DLO/TC 19/90III on 6/10/92	Since the Consultant admitted that environment assessment on the land-use implication would be made upon a final utilization/disposal decision he may as well say it in the Report. Then the decision-makers would be fully aware of this need for future action before they make the decision.	The need for further detailed environmental assessment is mentioned for options that will require it in the body of the report. This includes all new utilisation options and all disposal options. See for example Section 7. The need for such assessment is not however specifically mentioned in the Summary. This will be rectified in the Final Report.
57			I have not disputed against the various option for utilisation/disposal suggested by the Consultant. What my (101) in DLO/TM 150/5/42 II (TC 19/90 II) indicated are problems that are pertinent to each of the options suggested.	Noted. The SKIR has sought to identify these so that it can be determined if they can be resolved or not.

No.	Department	Reference	Comments	Consultant's Response
58			The Consultant's assumption for using the by-product for landfill and lagooning in the nearby area cannot be totally feasible as:	
			(a) The creation or reclamation of the areas in the vicinity of Black Point would be governed by their own development programme. They may not entirely fit in with the generation programme of the by-product.	Noted. Such facilities would only be considered if development programmes and ash availability permit. However as noted in comments 2(b) and 3(c) the use of PFA in reclamations and fill is to be encouraged as much as possible, by Government.
			(b) Once the areas have been filled or reclaimed, that is the end of the capacity. Yet the by-product generation is a continuous process. So the landfill suggestion is only a short-term measure.	The capacity of marine lagoons ML1 & ML2 is sufficient to take all PFA arisings until 2010 assuming none of the anticipated increases in utilisation. The landfills would last as long if not longer. The study brief specifies by-product management up to 2026 – the effective life of LTPS. If utilisation does increase then possibly no disposal facilities will be filled or a single disposal facility should be adequate and not a temporary solution.
			(c) For technical reason, the fill would not be 100% PFA. So the landfill sites may not be able to absorb the same amount of by-product as lagooning.	This would depend on development programs and settlement as described above. But the greater amount of PFA that can be used in the time available, the less PFA that would require long-term storage or disposal.
			(d) Whilst lagooning is controlled under the provisions of the Waste Disposal Ordinance it would demand a fairly long term tenure to absorb the amount of capital spent to fulfil the Ordinance's requirement. Yet, as far as the areas around Black Point is concerned, their respective programmed developments would not allow a long term occupation of such transilient user.	The principle objective of the study has been to examine potential options for the utilisation of by-products. Only in the event that utilisation fails is disposal considered. In considering both disposal and utilisation the impacts of transportation are also considered. Hence sites closer to CPPS & the LTPS are more favourable than those further away in general.

No.	Department	Reference	Comments	Consultant's Response
59			So in suggesting land for disposal purpose, the Consultant should not just indicated what can be available now, but also a programme of how the capacity of such land holds true for the purpose.	The issue of capacities of landfill sites and how these might be taken up at various utilisation rates are discussed in Sections 3.4, 4.4, 5.4, 6.4 and 7.
60			I have not overlooked Section 3.2.2 or Lamsonite. It is just that the Consultant instead of highlighting the capacity of China Cement, put only the emphasis on Concrete Blocks and Kin Ching Besser in Page V of the Executive Summary. I apology for not making it clear on this inconsistence in my earlier memo. In any case, I just want to stress the scarcity of land suitable and available for such utilisation process in Hong Kong.	It is only PFA that is suitable for cement clinker manufacture as summarised on page iii of the summary. Page v details FBA management. Your point on the general scarcity of land is noted. However, there are benefits to providing a few hectares for a utilisation plant near Black Point rather than a much larger area for a permanent disposal site and associated environmental impact.
61			Although it is environmental preferable to have the conversion of the by-product close to source, as the cost of conversion is not bored by CLP, much would depend on its contractors finding the conversion in Hong Kong economically attraction.	Noted.
62			Lastly I wish to point it is not just the *Planning Offices* that are involved in deciding the land/site availability issue; many government offices are involved.	Noted.

Large Thermal Power Station
Solid By-Product Study

No.	Department	Reference	Comments	Consultant's Response
1.	EMSD	G08/402V	I refer to DEP's memo ref. EP2/G/39 x dated 7.7.92 on the captioned report. The present concern is the unquantifiable utilization and disposal of FGD gypsum. The management strategy shall take into account the generation pattern of the coal fired units and any fallback option shall not affect the generating capacity of the station designed.	Noted.
2.	Geotechnical Engineering Office	(30) in GCP 1/10/445III	The following comments represent the views of the Geotechnical Engineering Office on the captioned report.	
			2. **General Comments** 2.1 In formulating the solid by-products management strategy, beneficial uses should be actively considered. Disposal should only be considered as a last resort.	Noted. The emphasis of the study is on utilisation first with disposal only considered for by-product not utilised.
			3. **Section 2.3 - Pulverised Fuel Ash (PFA)** 3.1 In Table 2.3(b) on page 28, the quoted typical values for effective cohesion of 20 kPa and 14 kPa for conditioned and leached PFA respectively appear to be higher than previously reported by Binnie Consultants Limited in their report entitled Pulverised Fuel Ash as a Reclamation Fill (which appears as reference no.39 on page 79).	Noted. Figures were supplied by CLPs engineers based on measured values. The effective parameters do not fully describe the variation in the properties of PFA; the text will be changed to "up to 20 kPA and 14 kPA" respectively, to illustrate the range of values encountered.

No.	Department	Reference	Comments	Consultant's Response
			4. Section 3 - Pulverised Fuel Ash (PFA) Management 4.1 The active use of PFA as reclamation fill was endorsed by the Land Development Progress Committee in March 1992. In principle, Government is prepared to enter into agreement with CLP whereby the PFA produced would be harvested from time to time by Government contractors for use in reclamation projects. The existing Tsang Tsui lagoons should be more than sufficient to act as a temporary storage facility of PFA for subsequent use in reclamations.	Noted.
			4.2 Subject to a successful agreement being reached between Government and CLP, the whole issue of PFA disposal could disappear and all arisings put to beneficial use. It is also likely that Furnace Bottom Ash (FBA) could be utilised as fill material in a similar manner.	Noted.
3.	Government Secretariat (Economic Services)	(5) in SBCR 7/2061/90	British Forces have been consulted on the proposed landfill sites in the Castle Peak Firing Range discussed in section 3.3.3 (page 99) of the draft final report. They have pointed out that they have already cooperated with a number of requests to use parts of the Castle Peak Range and that as a result the space on Castle Peak available for military training has become restricted. The position has now been reached where they are unable to give further consideration to the formation of any more landfill sites there, unless alternative training facilities are reprovided elsewhere. British Forces will continue to use Castle Peak Firing Range until mid-1997. As stated in the report, the situation after 1997 remains uncertain.	Noted. The Study assumes sites in the firing range are not available prior to 1997, but it is anticipated that a more strategic view may be taken post 1997.

No.	Department	Reference	Comments	Consultant's Response
4.	Highways Dept	( ) in HNT/705/TM/109	I refer to EPD's memo ref EP2/G/39X dated 7th July 1992 addressed to me among others and copied to you on the above subject. I confirm that I have no comments on the Solid By-products Key Issue Assessment Report.	Noted.
5.	PM/Tuen Mun	(68) in TM 5/4/138 Pt.2	I refer to your memo under reference enclosing a copy of the captioned report for my comment. 2. I have no particular comments on the report, noting the consultants' recommendations that the proposed marine lagoons ML1 and ML2 are not considered viable to develop due to the presence of the proposed Tuen Mun Port Development. 3. With regard to the consultants' proposal to raise the level of the existing PFA lagoons, please note that the height and final contouring of the PFA lagoons shall meet Government's requirement and shall be subject to Government's approval.	Noted, this constraint is brought out in the report. Whilst not available as dedicated lagoons, these reclamations are well located to incorporate any available PFA within them. Noted.
6.	Marine Dept	(2) in PA/S 909/6/8	In response to memo No.EP2/G/39X dated 7 July 1992, from the Director of Environmental Protection, my comments on your Study for the Disposal of Solid By-products are: Since the Study is only an assessment of the possible options for the disposal of solid by-products, from a marine point of view, I would have no objections in principle, to the preferred option provided that: (a) All individual applications are considered and agreed by me and the Fill Management Committee; and (b) Adequate precautions are taken against siltation.	Noted. Noted. Any firm proposal would require detailed assessment as noted in the report.

No.	Department	Reference	Comments	Consultant's Response
7.	Regional Services Dept	(25) in RSD 24/HQ 500/89 VI	I have no comments on the draft final report.	Noted.
8.	District Lands Office, Tuen Mun	(101) in DLO/TM 150/5/42 II	I refer to the above study report sent over by the Director of Environmental Protection for comment. The report placed focus only on the possible utilisation and disposal of the by-products so that they would not consider as environmental nuisance at all. In so doing, it understated the environment impact on the land that needs to be engaged for the utilisation and disposal process. As far as the Land Administration Office is concerned, there are problems in maintaining or creating the quantum of land for the purpose of these by-products' utilisation or disposal. With regard to utilisation, there are few sites available locally for the manufacturing process involving any of the by-products. Within Tuen Mun and in direct contract relationship with CLP for the processing of the PFA, there are the China Cement Plant and Kin Ching Besser Plant. (Only the latter was mentioned in the report, i.e. page v of the Executive Summary). It is evident that these plants cannot be considered as environmentally friendly user in the fast growing Tuen Mun New Town. Especially for the latter, Kin Ching Besser Co., whose occupation of land is only on short term tenancy basis, would soon be asked to surrender back the land for other parmanent development. Elswhere, the availability of land for cement, concrete block processing are diminishing. In any case, it would be environmentally and traffic-wise undesirable to transport the PFA etc. on road to the processing destinations. The other possible venue for utilisation of the by-product involving the processing operation may be by export. All in all, the report did not seem to have addressed the environmental issue attached the quantum and location of land for by-product utilisation involving the processing operation fully.	Points below appear pertinant: Any firm proposal for utilisation or disposal of by-products would require an assessment of environmental issues in detail and this would include implications of land-use. Large areas of land are due to be created in the vicinity of the new power station (Tuen Mun Port, Area 38 etc.) and potentially this could be used for utilisation of by-product in preference to landfill or lagooning. China Cement Plant is mentioned extensively in the report (e.g. Section 3.2.2). The proposed use of land for productive industries is not considered to conflict with the local development plans. From an environmental point of view it is preferable that PFA and FBA are converted to useful products, as close to their point of origin as possible.

No.	Department	Reference	Comments	Consultant's Response
			Similarly, I have reservation on the quantum of land you claim to be available for by-product disposal. I do not dispute against the possibilities highlighted in your Fig.3.3 (a) on page 91 of the report. However, except for the Tsang Tsui Lagoons, all the other possible disposal sites suggested in the said figure would be subject to Government's considerations. The Marine Lagoons 3 and 4 would obviously be very disruptive for the Mai Po/Deep Bay habitat, and no doubt the Director of Environmental Protection and the Director of Agriculture and Fisheries would contribute their expert views. As for the rest of your suggestion, namely; Marine Lagoons 1 and 2, Landfill 1, 2, 4 and Quarry Q1 and Q2, I must point out that the implication of timing for their final land use development may not prove entirely in concerto with your suggestions.	The precise quantities of land suggested for allocation to ash-based industry is subject to discussion. However, such an allocation would appear to be both necessary and desirable for long term planning in the area. It is understood that the planning process in Hong Kong ensures that all developments are subjected to Government's consideration. Marine lagoons 3 and 4 were not recommended in the study due to environmental concerns. The study is intended to investigate options for disposal/utilisation of by-products considering the overall engineering, economic and environmental issues such that a detailed strategy may be affected. The overall benefits/disadvantages of each option must be considered. The specific timing of each of the sites will be dependent upon the precision of the Planning Offices estimates of the time of site availability and will require further discussion as specific sites are progressed.
9.	Planning Dept	(23) in PDTM 1/1/59 Pt2	I refer to DEP's memo EP2/G/39X dated 7.7.92 enclosing a copy of the subject draft report and wish to advise you that I have no comment on the contents contained in the report.	Noted.
10.	Government Secretariat	(51) in ESB CR 5/4576/78 (91) XII	I refer to the memo from the Director of Environmental Protection dated 7.7.1992 enclosing the SKIA report. Please be informed that I have no comments on the report.	Noted.

No.	Department	Reference	Comments	Consultant's Response
11.	Civil Aviation Dept	(22) in WKS/659 III	I received a copy of the SKIA report from the Director of Environmental Protection who requested all comments to be directed to ERL. Since the area of discussions does not concern aviation, I have no comment to make.`	 Noted.
12.	Agriculture & Fisheries Dept	(27) in AF DVL 01/72 IV	Use of the solid waste in the manufacturing of products which can be sold on commercial basis should be encouraged. For example, the use of PFA in concrete and cement, FBA in concrete block and aggregate replacement, and export of gypsum to overseas market.	Noted and agreed.
13.			Marine dumping of the solid waste in Hong Kong or international waters is not supported as there may be adverse impacts on the marine ecosystem arising from sterilisation of the seabed, leaching and dissolution of toxic metals.	Noted. Marine dumping is not a favoured option but considered in the report so as to examine its feasibility, and would be considered as a less favoured option in respect of ash.
14.			There seems to be no capture fisheries implications for the existing PFA lagoon. If, however, new marine lagoons are to be formed, there is great potential for opposition from the fisherman.	Noted, detailed study and assessment would be required.
15.			The proposed ML4 would completely destroy the Pak Nai SSSI which is important for its sandpit. It is being used as high tide roost site for gulls and terns in the Deep Bay area, the only such site in Hong Kong. Therefore, the location of ML4 is strongly objected.	Both ML4 and ML3 were rejected on the grounds you mention.
16.			The proposed LF1 and LF2 are very close to the Castle Peak SSSI which is important for its rare plant species. There may be some protected plants exist in your proposed LF sites, therefore detailed studies would be required for the flora and fauna before the sites could be committed for the purpose.	Noted. We understand that this site has already been subjected to detailed examination by others as a borrow area for the construction of CLK airport, and anticipate that mitigation measures for protected species on the site would be taken before borrowing commenced.

No.	Department	Reference	Comments	Consultant's Response
17.			The proposed LF4 is very likely to cause water pollution through surface runoff and leaching and affect the Pak Nai SSSI. Also, LF4 is close to Pak Nai Village where there is active and substantial agricultural activities and fish farming. Please note that Pak Nai is being identified as an extension area for Agricultural Land Rehabilitation Scheme. The location of LF4 is, therefore, not supported.	Noted. These issues were considered in the report and would be investigated further if this option were pursued, and appropriate mitigation measures proposed if required.
18.			The use of PFA in landscape restoration of quarry sites may be further explored if PFA is proved to be suitable for plant growth.	Noted. CLP have already carried out extensive planting trials, with considerable success.
19.			Re-dissolution of gypsum in seawater and discharge to sea is not in favour until it can be proved beyond doubt that it is environmentally acceptable and has no adverse impacts on capture fisheries.	Noted. This issue is discussed in the parallel Water Quality Key Issue Assessment.
20.			Study on reef construction with gypsum is still in experimental stage and it should not be taken as a solution to dispose gypsum.	Noted. This is a conclusion of the study.

Annex 1

Revised Table 2.5(c)

Table 2.5(c)
Chemical Analyses of FGD Gypsum

	Riedersbach FGD Gypsum	Voerde FGD Gypsum	Steinkhole FGD Gypsum		Modelled LTPS FGD Gypsum
			Modelled	Actual	
Moisture loss @20°C (%)	5.4%	8.4%	–	–	–
pH	7.1	6.7	–	–	–
Electrical Conductivity (μs/cm)	1650	1750	–	–	–
Total Alkalinity ($CaCO_3$)	26500	4,500	–	–	–
Calcium (Ca)	20.7%	20.1%	–	–	–
Magnesium (Mg)	113	46	–	–	–
Sodium (Na)	2340	1760	–	–	–
Chloride (Cl)	20	40	–	–	–
Floride (F)	140	90	–	–	–
Sulphite (SO_3)	<50	<50	–	–	–
Sulphate (SO_4)	51.7%	50.5%	–	–	–
Silicon (Si)	375	470	–	–	–
Iron (Fe)	340	250	–	–	–
Aluminium (Al)	100	200	–	–	–
Boron (B)	<10	<10	–	–	–
Arsenic (As)	<1	2.1	0.53	0.50	0.67
Cadmium (Cd)	–	–	0.17	0.062	0.83
Chromium (Cr)	–	–	0.70	0.71	3.35
Copper (Cu)	17	<10	1.13	0.80	1.50
Mercury (Hg)	0.08	0.08	0.16	0.09	0.25
Molyedenum (Mo)	23	65	–	–	–
Nickel (Ni)	27	12	0.73	0.41	3.88
Lead (Pb)	–	–	6.26	5.76	1.47
Zinc (Zn)	–	–	17.60	13.30	5.79
Selenium (Se)	2.6	<1	–	–	0.43
Antimony (Sb)	–	–	0.17	–	–
Total Inorganic Phosphate (PO_4)	<200	<200	–	–	–
Nitrate (NO_3 – N)	13	16	–	–	–

Notes : All results expressed as mg/kg dry basis except where specified.
– Data not available LTPS modelled figures for indicative purposes only – will vary with feedstock composition.

Annex F

Solid By-products KIR Response to Comments - EPD Consolidated Comments Annex to Position Statement

WMPG

General

i) Our stance on the solid by-products management strategy for the LTPS is as follows:

a) we prefer the utilisation options as the long term management strategy for the solid by-products of the LTPS; and

b) we have strong reservations on "local disposal" of these solid by-products. However, we can accept "temporary storage", e.g. lagooning for PFA, as a fall-back strategy provided that there is a definitive duration for the fall-back scenario.

ii) It should also be noted that utilisation potentials of FGD gypsum have not been carefully examined and strong reservations on the seawater disposal option were expressed by this department. Options for beneficial use such as export to other countries need to be assessed with greater effort. We do not agree that "the focus of the management strategy is prevention of arisings via discharge of dissolved gypsum to sea in preference to utilisation or disposal of solid gypsum" (re: Para 1, Page viii, Executive Summary, SKIR) as FGD gypsum is itself an usable resource and should therefore be used rather than disposed of whenever possible.

iii) It is our general view that gas firing is preferred for the LTPS but we understand that coal-firing has not been precluded. If coal-firing is to be adopted by CLP, we expect a more detailed study on the long term management strategy of the solid by-products, the utilisation options (local use and exportation) of FGD gypsum in particular. Sufficient time must be allowed for the study and for government to comment.

iv) It is expected that the SKIR will be referred to by CLP or their consultants in further investigation/development of the management strategy. The views from different government departments on the SKIR should therefore be incorporated in, or as least attached to, the report. A fair document of the comments, response to comments and further comments on the report can be issued as an appendix or supplementary notes to the report.

Item 3(c)

The use of PFA as fill material in reclamation project should be a preferred option. The disposal options at dedicated landfills may no longer be required. CLP is requested to approach GEO/CED on the detailed arrangement for use of PFA in reclamation works.

Item 3(d)

We maintain our original view that " the preferred option for FGD gypsum is beneficial use. Export to other countries is considered better than disposal in Hong Kong". Dissolution of FGD gypsum in cooling water should not be the preferred solution, from a waste management viewpoint.

Item 13

We don't think that our acceptance of the provision of back-up facilities/site for buffer storage of the solid by-products in any fall-back scenario "negate" our line of "no disposal" within Hong Kong, provided that there is a definitive duration for the fall-back scenario.

LCG

Item 28(a) and (c)

Comments on the dissolution of gypsum are dealt with in EPD's comments on the Water Quality KIR.

Item 28(b)

We disagree. The dissolution of gypsum in freshwater, process water or the receiving seawater is not merely a 'claim/guarantee' that can be offered by any vendor; it is a concern (based on the physical properties of gypsum) especially with the significant potential impact that such a large load of gypsum has on the marine environment.

Item 28(d)

We disagree. The impacts of decantrate have not been fully addressed in the Water Quality KIR. PFA decantrate was not included in the summary of effluent flows in Table 2.1(a) of the Water Quality KIR.

Item 28(e) & 29

Noted.

Item 30

Noted. The consultants should approach the FMC for information on the current development concerning fill management.

Item 31

We disagree. Putting aside the difference in view on the dissolution of gypsum in seawater, even if we were to assume that the seawater FGD system produces 'dissolved' gypsum, there would still be other contaminants (eg toxic metals) contained in the same 'solution/suspension' and their loads/impact should be assessed. Our reservations are clearly stated in our comments to the Water Quality KIR.

Item 32

Same as item 28(a).

Item 33, 34 & 35

Noted. Presumably the validity of these statements have been confirmed by the consultants.

WPG

General

The aim of the SKIA is to address the feasibility of individual options for the management of solid by-products generated by the LTPS. Answers to our queries in item 42(c)(d), 44 & 45 are necessary to establish the technical practicality & environmental acceptability of the options. These issues must be recorded as items for further assessment when CLP decide to use coal as the generation fuel.

Item 36(c)

The consultants have not responded to the queries about the setting up of a pilot plant which they have said in the report.

Item 40

Regarding the consultants' proposal to use silt screen to entrain PFA, was there any successful trial and what was the result?

Item 43

Item 32(d) cannot be found.

Item 47

In the draft Water Quality KIR, the seawater FGD process was hardly mentioned. Would the consultants update the relevant section?

Item 52

i) It seems that the consultants are pressing ahead the seawater FGD system/re-dissolution system and repeatedly quote the WQKIR that "the dissolution of gypsum will not cause significant environmental impacts with respect to appropriate criteria". However, re-dissolution of gypsum will involve a discharge of about 400,000 ton per year of gypsum (Solid by-product KIR, page 164) into the sea which includes about 5% of insoluble constituents, insoluble PFA particles as well as toxic metals. The WQKIR has failed to demonstrate that it is an environmentally acceptable option. Our strong reservations have been clearly stated in our comments on the WQKIR.

ii) Although the consultants' response hinted that all gypsum would be dissolved at the point of discharge, there is an indication in the SKIR that a significant amount (about 20,000 ton per year) of insoluble constituents of gypsum would be discharged into the marine environment. Complete dissolution at discharge point might also mean quick local precipitation because of local saturation of gypsum due to tidal current effect.

Item 2(c)

The proposal to discharge dissolved gypsum and the suggested subsequent reduction in disbenefit are questionable. This appears to seek a mere transfer of pollution from one medium to another (ie from air to water). The objective must be the prevention of significant environmental impact.

Item 36(a) & (b)

Response offered is not very positive, leaving options open to the proponent.

Item 52(a)

The rapid current in Urmston Road cannot be relied on to disperse the pollutants. Dispersion modelling in the report shows that, for instance, the effluent would make significant movement into Deep Bay, thus allowing deposition of suspended material to take place.

Item 52(b)

Any marine studies would surely have some significance in supporting this contentious proposal.