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25 September 2002

Ms. Maggie Wojtarowitz, E.I.T.
Project Engineer
EcoSmart Concrete
504-999 Canada Place
Vancouver, BC V6C 3E1

Dear Maggie:

Reference: NLK Project EA2860
EcoSmart Concrete Project
Metakaolin Pre-Feasibility Study

NLK Consultants Inc. (NLK) has conducted an independent metakaolin pre-feasibility review of the potential for developing metakaolin (MK) from the oil sands operations for use in concrete as a supplementary cementitious material (SCM). We have brought together information through literature searches and input from researchers and specifiers, cementitious material suppliers, ready mix concrete suppliers, end-users and industry associations. We have addressed the technical, economic and environmental issues. This initial work addresses Phase 1 of the terms of reference.

The final report for our study is enclosed.

We have enjoyed working with you on this project and look forward to continued involvement in the future.

Sincerely,

R.A. Mitchell

R.A. Mitchell
Manager, Process Group

RAM/ram
Enclosure

c: File 121.701

NLK PROJECT EA2860
25 SEPTEMBER 2002

ECOSMART CONCRETE
VANCOUVER, BC

ECOSMART CONCRETE PROJECT
METAKAOLIN PRE-FEASIBILITY STUDY

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EXECUTIVE SUMMARY

INTRODUCTION

The EcoSmart^{TM} Concrete Project has an objective of reducing the greenhouse gas emissions by replacing Portland cement (PC) in the concrete mix with supplementary cementitious materials (SCM). One such potential SCM is metakaolin (MK), which is produced by heating kaolin to remove water of hydration. For this reason, MK is also referred to as calcined clay.

The oil sands tailings ponds in northern Alberta are a potential source of kaolin from which MK could be produced for use as an SCM. This independent metakaolin pre-feasibility study by NLK Consultants Inc. (NLK) considers the technical, economic and environmental aspects of recovering and converting kaolin to MK and of using MK as an SCM. In conducting the study, NLK collected existing information from industry and research organizations using literature searches and phone interviews.

This phase of the study initially assumed that the technology to extract kaolin from the tailings ponds and produce MK as presented in the Syncrude Kaolin Recovery Project reported by Tynebridge Technologies Limited in 1998 was feasible. Study analysis revealed that the economic returns from such a plant were very marginal. As a result, a very preliminary analysis of a much larger plant, using existing calcining capacity, was conducted. This large plant could take advantage of lower production costs and the corresponding increase in potential product demand. Economic returns for a much larger plant appear promising enough to warrant additional investigation.

CONCLUSIONS and RECOMMENDATIONS

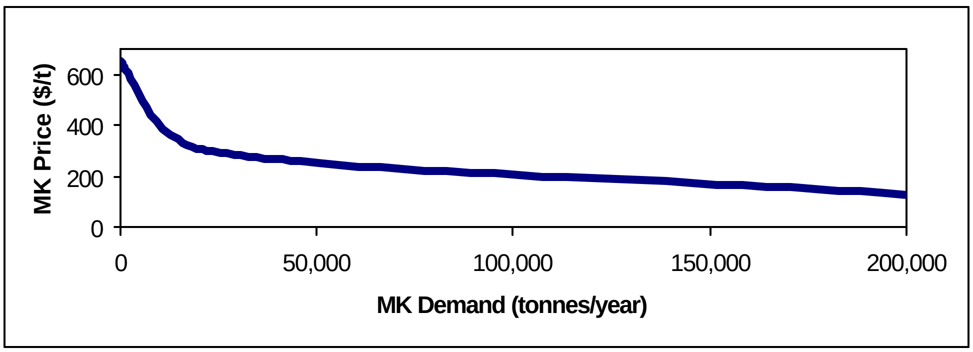
MK produced from the oil sands tailings is comparable to silica fume (SF) as a concrete additive and is about 85-90% as reactive as commercially available MK. It is technically viable for use as an SCM in concrete, however its slight colouration precludes it from the major, commercial MK end-uses in paper and paint pigments. At the current price of about $650/tonne, demand for commercial MK in concrete in Western Canada is essentially zero.

A precondition to considering the viability of extracted MK is that it can be supplied at a low enough cost to provide economic benefits to ready mix concrete suppliers with resulting demand that is adequate to justify an extraction plant. NLK assessed the tailings extraction plant economics as scoped in the 1998, Tynebridge study [2] and reviewed ready mix concrete supplier costs. A delivered price of $300/tonne can provide a marginal return on capital employed for the extraction plant and provide ready mix suppliers with nominal savings for some of their batches. This assumes that the MK allowed a 10%

reduction in total cementitious materials (CM) for higher strength concretes, when used in ternary blends with fly ash (FA). Possible demand for MK priced at this level is estimated to be in the range of 20-24,000 tonnes/year in Western Canada.

The analysis indicates that returns to the stakeholders (ready mix suppliers, CM suppliers, oil sands plants), are such that it is unlikely any of them would 'champion' the project and move it forward on this basis. However, a number of the market research respondents stated that if the extracted MK price level could approach that of PC ($130/tonne), there could be significant savings to ready mix suppliers and increased demand. Demand for MK priced in the $130/tonne range is projected at 200,000 tonnes/year in Western Canada. Thus three price/demand relationships are available for MK from which to draw the following demand curve:

Figure 2.01
MK Demand Curve



As MK pricing approaches that of PC, demand increases such that it could support a plant large enough to be relevant to the oil sands plant operators, and to have more impact on reduction of greenhouse gas emissions. For example, an extraction plant with a capacity in the order of 1 million tonnes/year may remove enough colloidal material from the tailings ponds to provide significant economic and environmental benefits to the oil sands operations. Credits for recovery of bitumen, reduction of fresh water usage and effluent treatment costs could offset some of the extraction plant capital. Since extracted MK will displace PC, it may be possible to utilize existing kiln capacity for calcining the kaolin, further reducing the plant's capital requirements and enhancing its viability. In order to achieve plant economies of scale that may enable MK price levels as low as PC, markets in the US and offshore will be required. However, it should be noted that penetration of large volumes of extracted MK into an undeveloped market is not plausible. Therefore, process concepts allowing incremental installation and start-up of the extraction facility must be explored.

It can be concluded that the demand level and economic benefits of extracted MK, based on the plant scoped in the Tynebridge study and priced in the range of $300/tonne, would be difficult to justify a business case for further effort on this project. However, the potential demand for MK priced at a similar level to that of PC could be of such significance to all of the stakeholders, that a different approach should be considered in assessing the viability of a much larger extraction plant. The following assessments and analyses are recommended to test this approach:

a. Conduct concrete tests using purchased MK to confirm the economic efficiency of iso-strength, ternary blends of PC/FA/MK at various CM and strength levels, in providing economic benefits to ready mix suppliers. If these tests show promise, then conduct further tests on MK produced from the oil sands tailings.

b. Assess extraction plant economies of scale that could enable MK priced at a similar level to PC and provide some incentives to oil sands operators. Capacities in the range of 1 million tonnes/year may be required to achieve these objectives. A plant this size may remove enough kaolin and colloidal material from the tailings ponds to provide significant environmental and economic benefits to the oil sands operations. Included in this analysis should be the following:

   1. Evaluate synergies with the oil sands plants' effluent systems that may enable increased recycling of water and reduced environmental liabilities and perhaps offset some of the extraction plant capital.

   2. Assess the potential of using existing cement kiln capacity to calcine the extracted kaolin and avoid the capital of an on-site calciner.

   3. Evaluate the potential of reducing transportation costs with the use of high volume unit trains that are used for coal and sulphur. Freight cost in the order of $50/tonne from Ft. McMurray to Vancouver should be possible.

   4. Assess extraction plant concepts, perhaps based on multiple, parallel process lines, that may allow incremental installation and start-up of the plant and gradual phase-in of the total capacity as markets develop.

c. Assess the California and offshore Japan/Asia markets re: the potential demand for MK. Included should be a segmentation of these concrete markets for the following criteria:

   1. Strength

   2. Workability

   3. Durability

   4. Aesthetic aspect

   Quantification of these segments should enable a more precise estimate of the areas where MK can penetrate the CM market.

d. Upon establishing the extraction process concept, conduct a sensitivity analysis on plant capacity vs. return on capital. Prepare a feasibility grade capital cost estimate on the optimum sized facility.

e. Consider alternate sources of MK such as sludge from deinking plants that could develop the CM market for this product.

f. Assess other end uses for extracted MK such as automobile tires or fibre cement board.

MARKET RESEARCH

A preliminary literature search and desk analysis was conducted to provide background for a market research study on the viability of extracting MK from oil sands tailing ponds as an SCM in concrete. A total of 21 telephone and personal interviews were completed with researchers and specifiers, cementitious material suppliers (PC and FA as well as other additives), ready mix concrete suppliers, end-users and industry associations. The following summarizes key issues and conclusions that can be drawn from this work:

a. Extracted MK is similar to SF in the properties it imparts to concrete. However, demand as a substitute for SF is too small to be relevant to the economics of an extraction plant.

b. A precondition to considering the viability of extracted MK is that it can be supplied at a low enough cost to provide economic benefits to ready mix concrete suppliers with resulting demand that is adequate to justify an extraction plant. The integrated suppliers of PC and FA, based on their preliminary review of the economics of an MK extraction plant and their estimates of the delivered cost of the material, could not find a business case to warrant further effort on this project.

c. Ready mix suppliers are very sensitive to the cost of their inputs and have their batch recipes finely tuned to optimize their costs. They are continually searching for opportunities to lower their costs while maintaining or improving quality and performance. They would require enough savings to justify the cost of an additional silo at $70-$100,000.

d. NLK's analysis of the extraction plant economics indicate that MK can be delivered to ready mix plants at a price level of $280-$300/tonne and provide a return to the extraction plant capital employed. At this price level, a 5% replacement of PC with extracted MK would have to enable a 10% reduction in total CM in a ternary blend of PC/FA/MK, in order to provide a savings of $0.50-$1.00/m^3 of concrete.

e. 25-30% of the concrete market is of high enough strength to potentially enable a 10% reduction in CM. Therefore, a ready mix plant must be well enough positioned to the commercial market to require a volume of 20,000-40,000 m^3/year of higher strength concrete to justify the cost of an additional silo.

f. Additional economic benefits to a ready mix supplier may be the possible substitution of SF with lower cost MK providing a savings in the order of $500/tonne compared with the current cost of SF. Although not material to the economics of an extraction plant, savings of $50,000/year could be available to a ready mix plant supplying 100 tonnes/year of SF in concrete as well as the avoided cost of a new silo.

g. Potential demand in Western Canada for extracted MK in ternary blends, under these conditions is in the range of 20-24,000 tonnes/year. Markets in the adjacent US northwest, which would require similar freight rates to those used in this study, must be included in the demand analysis to justify a 30-40,000 tonne/year extraction plant which was the basis of NLK's delivered cost estimate for MK.

Although supported by our preliminary literature search, savings to the ready mix suppliers are based on the assumption that a 5% replacement of PC in a ternary blend with FA can enable a 10% reduction in total CM for the same concrete strength level. Tests must be done that assess the economic efficiency of ternary, iso-strength blends with various levels of CM and FA/PC/MK ratios. Confirmation of adequate reduction in CM to enable savings for the ready mix supplier, may justify additional trial and plant feasibility work. However, if cost savings are not confirmed, additional work on this issue may not be justified.

A number of respondents indicated MK would have to be priced at the same level as PC in order to have significant demand for the product. Demand for MK at a price of $130/tonne is projected at 200,000 tonnes/year in Western Canada, based on our assumptions that ready mix suppliers could optimize their batch costs by using ternary blends of 60% PC, 25% FA and 15% MK, for most of their end uses.

COSTS

Capital Cost and Investment

In 1998 Tynebridge estimated a capital cost of $32 million for a plant capable of producing 22,000 tonnes/year of MK during 5,000 operating hours.

NLK has prepared a feasibility grade estimate of the capital cost (see Appendix 2) using the equipment proposed by Tynebridge, inflating the costs for major equipment and using NLK's experience and database to estimate construction and indirect costs. We have assumed that the plant could be built near the Syncrude extraction operation so some of the existing services could be accessed. Using this basis, we estimate the installed capital cost for the size of plant estimated by Tynebridge to be $24.3 million. We assumed that this plant would operate 8,400 hours/year to give a production capacity of 37,000 tonnes.

We also considered a larger plant to reduce the operating costs. We have assumed that a plant that is double the size would cost 1.8 times as much. Therefore, a feasibility grade capital cost for a 74,000 tonne/year plant is $43.7 million.

Finally, we gave brief consideration to a much larger plant that would be capable of extracting kaolin from all of the fine tailings from an oil sands operation. This plant would be ultimately capable of producing about 1 million tonnes/year of MK, and its cost could be in the range of $200 to $250 million. Capital costs may be significantly offset by credits for bitumen recovery, reduced effluent treatments costs and reduced fresh water consumption for the oil sands plants. This may allow the oil sands plants to possibly avoid capital costs in other areas. Additional capital may be avoided if existing kiln capacity can be used to convert the kaolin to MK.

Production Costs

The Tynebridge study calculated a production cost of $167/tonne of MK. This was based on an annual production of 22,000 tonnes. See Table 3.01.

NLK estimated the operating costs for a 37,000 tonne/year plant. The operating costs estimated by NLK when operating at maximum capacity are shown in the following tables.

Table 3.02
NLK Operating Costs (2002)
37,000 tonne/year

Item	Quantity	Unit	$/Unit	$/y	$/t
Manpower	22		$130,320	$2,867,000	$77.49
Reagents	12.863	Kg/t MK	$0.217	$103,300	$2.79
Natural Gas	3.26	GJ/t MK	$3.40	$410,100	$11.08
Power	158.86	KW/t MK	$0.044	$258,600	$6.99
Maintenance	5.5%	Equipment	$10,517,000	$578,450	$15.63
Total				$4,217,580	$113.99

A 74,000 tonne/year plant size lowers the operating costs to about $74/tonne MK.

A 1 million tonne/year plant would provide much lower costs. It is assumed that some waste heat from the oil sands operation could be utilized in the kaolin drying operation to provide about half of the heat requirement. Using the same unit costs as in the above table, the costs can be approximated as follows:

Table 3.04
Approximate Operating Costs (2002)
1,000,000 tonne/year

Item	Quantity	Unit	Separation $/t	Drying $/t	Calcining $/t	Total $/t
Manpower	29		$1.04	$1.69	$1.04	$3.78
Reagents	12.863	Kg/t MK	$2.79	$0.00	$0.00	$2.79
Natural Gas	3.26	GJ/t MK	$0.00	$5.54	$5.54	$11.08
Power	158.86	KW/t MK	$4.89	$1.05	$1.05	$6.99
Maintenance	4.0%	Equipment	$1.70	$1.06	$1.49	$4.25
Total			$10.43	$9.35	$9.12	$28.89

No credit has been taken for the bitumen that is recovered, however its value amounts to $6.34/tonne MK. This revenue could be used to reduce the cost of the separation step. At the very high production level, the reduction of green house gases (GHG) is significant and future CO_2 credits could be used to reduce operating costs.

TRANSPORTATION COSTS

Because of the remote location of the oil sands, transportation costs for MK are a very significant portion of the total delivered cost. For the 37,000 tonne/year plant, NLK has allowed $90/tonne. An additional $30/tonne was allowed for the 74,000 tonne/year plant due to a much larger market area.

However, for a very large facility, it may be possible to use dedicated unit trains and coastal barges to reduce transportation costs.

The star on the following map shows the location of Fort McMurray in north-eastern Alberta.

CASH FLOW ANALYSIS

The cash flow analysis for the 37,000 tonne/year plant is shown in Appendix 3. We have assumed that the plant would operate at reduced capacities of 50, 70 and 90% for the first three years of operation and achieve 100% capacity during subsequent years.

For a capital cost of $24.3 million, a selling price of $303/tonne MK results in an internal rate of return of 10%. If the bitumen credit is taken, the return improves to 11%.

A similar cash flow analysis for a 74,000 tonne/year plant (Appendix 3) indicated that a selling price of $282/tonne MK provides a 10% return of investment. Taking the bitumen credit increases the return to 11%.

For the very large facility, it may be possible to offset enough of the capital costs to enable a larger ROI, and with lower transportation costs, deliver MK at a similar price to that of PC.

TECHNICAL

Metakaolin Production and Technology

Kaolin is a naturally occurring substance formed by the erosion of the earth's surface. The deposits containing kaolin also contain sand, which must be removed prior to drying. In 1998, Syncrude retained Tynebridge Technologies Limited to develop a workable process and prepare a capital cost estimate. For the purposes of this report, the extraction process presented in the Tynebridge study [2] is assumed to be technically viable.

Although about 6 million tonnes of MK could be produced from the oil sands tailing, the potential market is small. NLK has estimated a plant with an annual production of 37,000 tonne MK, and considered the implications of a 74,000 tonne/year plant.

MK is produced by heating kaolin to drive off the water of hydration. This thermal activation of a mineral is also referred to as calcining, hence MK is also refer to a calcined clay. MK is presently produced from mined kaolin and has been used in concrete. Although there is presently no MK produced from oil sands tailings, MK from this source would be acceptable as an SCM.

Metakaolin as a SCM

MK is a pozzolan. It will improve the properties of concrete by removing calcium hydroxide (CH) produced by the hydration of cement. The partial replacement of PC by MK has been shown to increase compressive strength comparable to SF mixtures. MK use also improves concrete durability. It is generally acknowledged that MK adversely affects concrete workability, although less so than SF.

A research update [29] indicated that the performance of the MK from oil sand tailings was about 85-90% of the pure MK and slightly less than SF

Experience with MK in concrete is very limited, mainly as an alternative to silica fume for use in concrete requiring specific properties. We are not aware of any MK use in concrete in Canada.

The delivered cost of MK compared with PC and FA makes economic justification difficult. If MK in ternary blends permits reduction of the total cementitious component of conc rete, there may be some economic justification.

ENVIRONMENTAL IMPACT

As part of the development of an air quality management plan for the Lower Mainland and the Fraser Valley, the GVRD is investigating options to reduce the emissions of greenhouse gases. From the GVRD 2000 Emissions Inventory, GHG's totalled about 17.4 million tonnes as CO_2 equivalents, with contributions from the 'Non Metallic Minerals' sector (essentially cement production) representing some 11% of the total, or 1.9 million tonnes/year.

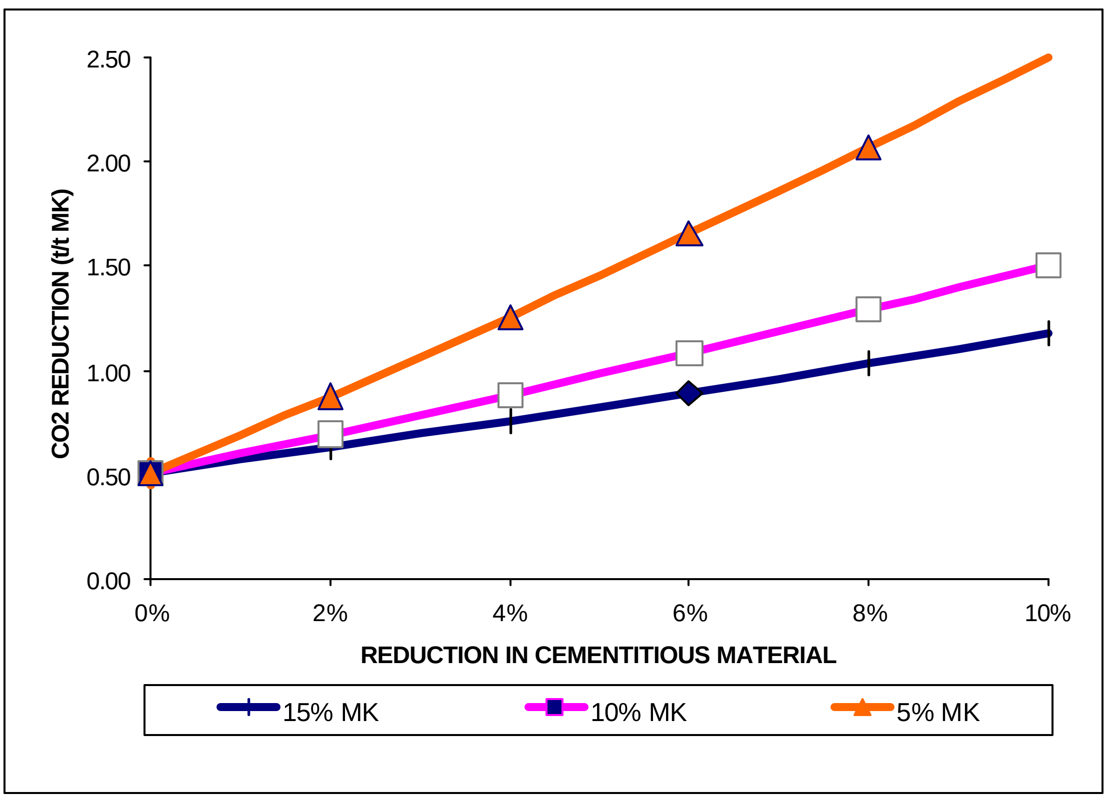
Replacement of part of the Portland cement (PC) in concrete with metakaolin (MK) as a SCM would contribute to a reduction in CO_2 emissions from the cement industry. A preliminary process (Figure 5.01) was developed by Tynebridge Technologies Ltd. (TTL) for the production of MK from MFT's at the oil sands plants in Ft. McMurray, Alberta. Projected yield on a dry weight basis would be 0.43 t MK/t MFT. Both the calciner and the dryer would be fired on natural gas. Using the energy value of residual bitumen in the feed to the calciner and in the flue gas, net fuel energy requirements for the process were estimated at 3.3 GJ/t MK produced.

Environmental impact of the TTL process would essentially comprise emissions to atmosphere from the dryer, which would be equipped with a baghouse. Emissions were estimated for three GHG's (CO_2, N_2O, CH_4), CO, SO_2, NO_x and particulate (Table 5.01). For a MK production capacity of 37,000 tonnes/year, emissions from the production facility are minimal when compared to those from Syncrude and Suncor, and from Lower Mainland cement producers (Table 5.04). For a MK facility with a production capacity of 1,000,000 tonnes/year, estimated emissions are higher, however still well below those from the other sources.

Estimates of potential reduction in CO_2 emissions were developed for 0-15% replacement of PC in concrete with MK, for a reduction in total CM from 0 - 10% (Figure 5.02).

Figure 5.02

CO2 Reduction Per Tonne MK Used



Potential benefits that may accrue from the partial replacement of PC with MK include the following:

a. MK use in cement would contribute to a reduction in the CO_2 signature of concrete.

b. Within the limits of MK production capacity, recovery of kaolin from MFT's at the oil sands plants would have the potential to reduce the level of MFT's by about 43% based on the TTL process.

c. There would be no meaningful solid waste requiring separate disposal. Residual solids from the MK manufacturing process would be returned to the tailings ponds with effluent from the thickening process.

d. Dependent on the residual solids content, filtrate from the drum filter may be suitable for reuse within the oil sands processing plant, thereby reducing fresh water requirements. Based on the TTL process, volumes were estimated at about 16.6 m^3/hour.

e. Bitumen recovered in the TTL process (about 7,250 t/year) would be available to improve oil recovery efficiency from the tar sands. This is based on a MK production capacity of 37,000 t/year.

f. The MK demand curve (Figure 2.01) shows that as manufacturing costs decrease towards those for PC, the potential viability is enhanced for a large scale process facility in Ft. McMurray with a production approaching one million tonnes per annum. A plant of this size would contribute to a significant decrease in the GHG signature for concrete, and may warrant further consideration.

Potential disadvantages would include:

a. Drying and calcining of kaolin from MFT's would require natural gas. For a MK production capacity of 37,000 t/year, gas requirements would represent about 120,250 GJ/year (3.25 GJ/t MK). Residual bitumen in the feed to the calciner represents about 0.85 GJ/t MK and was applied as a credit in calculating the natural gas requirements. Total fuel energy requirements for MK production were estimated at 4.1 GJ/t MK.

b. Operation of the calciner and dryer would result in the emission of other contaminants to atmosphere (Table 5.01). These emissions are minimal when compared to those from the oil sands plants in Ft. McMurray and cement manufacture in the Lower Mainland. (Table 5.04).

c. Production of MK from MFT's at Ft. McMurray would result in an increase in CO_2 emissions of about 0.37 t/t MK. Generation of other GHG's would be minor.

d. Transportation of MK from Ft. McMurray to Vancouver would increase CO_2 emissions by about 0.022 t/t MK or some 815 t/year (for 37,000 t MK/year).

METAKAOLIN PRE-FEASIBILITY STUDY

1.00 INTRODUCTION

The objective of the EcoSmart^{TM} Concrete Project is to minimize greenhouse gas (GHG) emissions by replacing Portland cement (PC) in the concrete mix with supplementary cementitious materials (SCM). Replacement will be to the greatest extent possible while maintaining or improving costs, performance and constructability. One of the key factors in achieving this objective is identifying and evaluating the availability and applicability of potential SCM's. One such potential SCM is metakaolin (MK).

This independent metakaolin pre-feasibility study by NLK Consultants Inc. (NLK) investigates Phase 1 of the possibility of recovering kaolin from the oil sands tailings, converting the kaolin to MK then using the MK as an SCM. A second phase identifying business, industry and government drivers for further developing the technology would be undertaken if Phase 1 brought positive conclusions. NLK collected existing information from industry and research organizations using literature searches and phone interviews. The study considers the technical, economic and environmental aspects of recovering and converting kaolin to MK and of using MK as an SCM.

The market research is presented in Section 2.00, costs are discussed in Section 3.00, technical aspects of the study are in Section 4.00, the environmental issues are addressed in Section 5.00 and the conclusions and recommendations are in Section 6. The references are listed in Section 7.00.

2.00 MARKET RESEARCH

2.01 Approach and Methodology

Our approach to this study included both a literature search and personal interviews with industry participants.

2.02 Desk Research

Included in the literature search was an internet survey of the concrete industry and supply/demand of SCM's. In addition, information was gathered from key articles on the use of SCM's in concrete that were provided by the EcoSmart™ project and forwarded by some of the interview respondents

2.03 Personal Interviews

Based on conclusions drawn from the literature search, a draft questionnaire was developed as a guideline for the personal interviews with the respective respondents. The questionnaire is shown in Appendix 4. Specific questionnaire guidelines were developed for each group of respondents:

a. Researchers

The first interviews were planned with research groups having done work on the use of MK in concrete. The main objective was to provide a comparison of MK with other SCM's, particularly SF.

b. Cementitious Material (CM) Suppliers

This group includes suppliers of PC, as well as SCM's. The objective was to assess their views on the potential for MK at various price levels and its possible synergy with other SCM's. A secondary objective was to provide more background on the economics of concrete in preparation for the interviews with concrete suppliers.

c. Concrete Suppliers

The objective of these interviews was to assess the price level required for MK to provide economic value to ready mix suppliers.

d. End-Users and Industry Associations

These were planned as follow-up interviews to confirm end-user performance requirements.

2.04 Desk Research Summary

a. Cementitious Materials Supply/Demand

Tables in Appendix 5 shows North American consumption of PC broken down by end-use and type, US production and consumption of FA, kaolin clay and ground granulated blast furnace slag (GGBFS) broken down by end-use. Although the focus of our study is primarily Western Canada, the following observations can be made from this more broadly based data:

1. Almost 90% of PC consumption is for general use. Only relatively small percentages are used for high early strength applications and in blended mixes with other SCM's.

2. The largest end-use for FA is as landfill. Only about 30% of FA is utilized in the US and of this, over 50% is used as a cementitious material.

3. The paper industry is by far the largest user of kaolin clay in the US, at almost 5.5 million tonnes. This includes both kaolin and MK (calcined clay) that, with its higher brightness, is used in paper coating formulations and filler for high brightness requirements. It should be noted that the lower brightness of the MK extracted from the oil sands tailing ponds would likely preclude this material from the paper end-use sector.

4. According to the US Geological Survey web-site, less than 1% of kaolin clay (including both kaolin and MK), or about 80,000 tonnes, is used in PC, either as clinker or SCM.

b. Cementitious Materials Pricing

Following are indicative pricing levels for the respective cementitious materials in Western Canada (in $CDN/tonne):

1. FA: $65-$75/tonne

2. GGBFS: $45/tonne; this material is not regularly used in Western Canada

3. SF: $650-$1000/tonne

4. MK: $ 630-$680/tonne

5. PC: $120-$130/tonne

The first two materials are lower cost than PC and are used primarily for cost reduction to the ready mix supplier. SF and MK are considerably more expensive than PC and are considered additives in that they are used to impart properties for specific applications.

SF is more broadly used in Western Canada as an additive than MK, which has very limited exposure in this region. Although specific consumption figures for SF in this region were unavailable, subsequent interview respondents stated that less that 1% of concrete requires it for high strength or durability applications. However, 90% of concrete contained FA. SF is a niche product additive in the concrete industry. Therefore, to attain a reasonable demand volume for MK, it has to approach a price level where it can be justified as a cost savings component in the more general use concrete category. Displacement of SF by MK would not provide adequate volume to be meaningful to the tailings pond extraction plant economics.

c. Key Articles

Relevant research articles on the use of MK in concrete, its comparison with SF and strength development in ternary blends with FA were forwarded by the EcoSmart™ project, CANMET and University of Calgary. We reference two of these articles as particularly significant to this study:

1. Jian et al. [31] compare the effect on concrete of MK and SF on workability, strength, shrinkage, and resistance to chloride ion penetration. They concluded that the increase in the strength of MK modified concrete was similar to the increase in strength of the SF modified concrete. Both materials significantly reduced the chloride diffusion rate, however, the SF concrete performed somewhat better. Additional articles comparing MK with SF in concrete are referenced in Section 4.02.

2. J. Bai et al. [32] explored the effects of various ternary blends of PC-MK-FA and water/binder ratios on the compressive strength of concrete at various stages. The article concluded that MK and FA complement each other as SCM's in concrete. Up to 15% partial cement replacement by MK resulted in considerable enhancement in strength in both the short and medium term. Judicious use of PC-FA-MK blends in concrete enabled a much-reduced PC requirement, while still maintaining or even enhancing the strength in the medium to long term.

d. Conclusions Drawn From The Desk Research

1. MK at its current price levels would be considered a concrete additive that is a competing product with SF.

2. The Tynebridge Technologies report on the Syncrude Kaolin Recovery Project indicated that, for a 22,000 tonne/year plant costing $32 million, a $600/tonne delivered selling price is required for the tailings pond derived MK to provide a 20%. At this price level there would clearly be insufficient demand for the MK to justify such a plant.

3. In order to be of economic benefit to the concrete ready mix suppliers and for demand to be adequate to justify a reasonably sized extraction plant, the MK must be priced much closer to the level of PC. MK costs to the ready mix supplier in excess of PC must be offset by other economic benefits such as the ability to use less cementitious materials for a significant segment of the concrete market, or sell the material at a higher price, etc.

4. Based on NLK's review and update of the Tynebridge study in Section 3.00, a $303/tonne delivered selling price for MK is required to provide a very marginal 10% return on capital for a 37,000 tonne/year plant. For a larger 74,000 tonne/year extraction and calcining plant with better economies of scale, a $282/tonne delivered price will give the same return. At these price levels it may be possible to provide marginal economic benefits to ready mix suppliers for higher strength concretes or in more broadly based ternary blends with FA, if enough offsetting costs can be obtained.

These preliminary conclusions established a direction for the market research in terms of phrasing the questions and probing the respondents for confirmation and offsetting costs and issues in dealing with an additional SCM.

2.05 Market Research Summary

A total of 18 individuals within the respective respondent groups were interviewed. Several of the individuals were interviewed twice, resulting in a total of 21 interviews. Six of the interviews were with researchers, seven with cementitious material suppliers, five with ready mix concrete suppliers and three with end-users and industry associations. Following is a brief synopsis of the comments and issues raised by the respective groups:

a. Researchers

Researchers confirmed that MK was generally comparable to SF in the properties that it imparts to concrete. There were numerous comments on specific properties of the two materials with some aspects being more positive for MK and others for SF. However, for purposes of this study, the comparable consensus is a relevant conclusion. One property of MK that may give it some advantages over SF in some markets is its colour. MK is relatively bright compared to SF, which darkens concrete. However, the size of the markets in which this may provide an advantage is likely not material to this study.

There was limited experience on the part of researchers with ternary blends of FA and MK. One researcher commented about ternary blends of 25-30% FA and 3-4% SF that improved early age strength and durability. One researcher kindly forwarded several articles on ternary blends incorporating MK that were done at the University of Glamorgan in Wales.

b. Cementitious Materials Suppliers

The large integrated cement companies that supply PC and FA to ready mix suppliers are included with distributors of additives to ready mix suppliers in this respondent group.

The suppliers of PC and FA had previously evaluated the MK extraction and calcining project from the oil sands tailings ponds, and did not find the MK viable as an SCM for the following reasons.

1. Their estimates of the delivered costs of the material to a region such as the lower mainland ranged from \$300-\$320/tonne including handling and distribution costs that one supplier indicated could be as high as \$40/tonne. At that price level there was no business case for this material. There would have to be a 10-15% reduction in total cementitious materials to provide any economic benefits to the ready mix supplier.

2. The material costs too much to displace low cost FA. There are other ways to increase the SCM content in cement. Their resources would be better spent improving the quality and processing of their FA and making it more consistent, enabling greater usage.

3. Demand for the high strength and specialty concrete that may require a material such as MK as an SCM is too small to justify the demand required by an extraction plant. Only about 1% of concrete is for very high strength or specialty applications that require SF.

4. Fort McMurray is too remote a location to source this material; transportation costs are too high.

The additive suppliers provided a more positive outlook on the potential for MK. However, their focus was on competition with, and possible replacement of, SF. They did identify the additional costs for a ready mix supplier to handle another SCM. The primary barrier would be the cost of an additional silo at \$70-\$100,000.

c. Ready Mix Suppliers

The ready mix suppliers were very open to any opportunities that could lower their costs. Their batch mix economics are finely tuned, and they are continually looking for ways to optimize their costs. When questioned about the potential for a lower cost MK in ternary blends, their response was as follows:

1. The initial response was for MK to be of any economic benefit and to be used in reasonably large volumes of concrete, it had to be priced in the range of PC at \$120-\$130/tonne. Several respondents, familiar with their parent companies earlier evaluation of MK, stated that \$300/tonne MK was simply a non-starter. NLK's preliminary analysis indicated a delivered cost of \$280/tonne to \$300/tonne for the MK would provide a marginal return for the extraction plant.

2. Additional savings must be available to the ready mix suppliers to justify using MK at these costs. There was agreement that 5% replacement of PC by SF could allow a 10% reduction in total cementitious materials (CM) for the same compressive strength levels. Given the similarity of MK to SF in the properties it imparts to concrete, it is plausible that a 5% replacement of PC by MK in a ternary blend with FA could enable a 10% reduction in total CM for the same strength levels with the following constraints.

   - There needs to be a minimum of CM in the concrete, otherwise there may be difficulty pumping and possibly void spaces. Only concretes with strength levels of 30 MPa and above have enough CM in their mixes to withstand a 10% reduction.

   - A $5/m^3 of concrete savings would be very interesting to ready mix suppliers. NLK's preliminary analysis indicated a savings of $0.50/m^3 to $1.00/m^3 of concrete with a ternary blend of 25% PC replacement with FA and 5% replacement with MK that results in a 10% reduction in total CM, compared to a control of 25% PC replacement with FA and no reduction in CM. There would have to be enough volume of higher strength concrete incorporating a ternary blend with MK that could payback a $70-$100,000 silo in 3-5 years. Thus, a ready mix plant would require a volume of higher strength, ternary blend concrete of 20-40,000 m^3/year to justify the cost of an additional silo.

   - Approximately 25-30% of the concrete sold in the lower mainland is 30 MPa and above. This could provide enough volume for ready mix plants that are well positioned in the commercial market to justify an additional silo. Plants with annual concrete volumes approaching 100,000 m^3/year and above, with 25% of their market at strength levels greater than 30 MPa, might consider an additional silo.

   - The potential for a 10% reduction in CM with ternary blends is hypothetical. Blend efficiency trials would have to be conducted to assess the performance of MK ternary blends with various levels of CM reduction.

   - Existing standards must be assessed as barriers to utilizing new materials such as MK.

d. Other Respondents

These respondents included a concrete specifier for a group of municipalities, a concrete consultant and an industry association. Key comments are as follows:

1. Structures built for municipalities such as water reservoirs, etc., require a life span of 75 to 100 years. The municipalities typically specify higher strengths than needed in order to get better quality and durability. The additional costs of the higher strength concrete mix are insignificant compared to the total cost of the structure.

2. The limited experience with ternary blends in Western Canada is a barrier to entry for MK in this role.

2.06 Analysis

a. Concrete Savings

The spreadsheet below shows cost savings per m^3 of concrete based on a 25% replacement of PC with FA and a 5% replacement with MK resulting in a 10% reduction in total CM, compared to a control of 25% PC replacement with FA and no reduction in CM. Two price levels for MK are used in this analysis; $303/tonne, which includes delivery and an allowance of $30/tonne for distribution and handling costs, for a 37,000 tonne extraction and calcining plant and $282/tonne for a 74,000 tonne plant. Cost details are shown in Appendix 6.

Table 2.01
Concrete Costs Summary

Material	PC Only	PC and FA	PC, FA and MK
	Kg/m3	Kg/m3	Kg/m3
MK	0	0	16
FA	0	90	81
PC	360	270	227
Total CM	360	360	324
Aggregate	1896	1896	1946
Water	144	144	130
Total Concrete	2400	2400	2400
Concrete Cost ($/$M^3$) -$303/t MK	**$75.24**	**$70.29**	**$69.66**
Concrete Cost ($/$M^3$) -$282/t MK	**$75.24**	**$70.29**	**$69.32**

Unit Costs ($/t): PC-$130, FA-$75, Aggregate-$15, Water-$0

Cost savings to the ready mix supplier range from $0.63 to $0.97 per cubic metre of concrete at these, delivered to the plant, MK costs. Although these savings are marginal, they are adequate to justify the costs of an additional silo for a ready mix plant that can supply 20,000-40,000 m^3/year of greater than 30 MPa concrete.

There may be additional savings for ready mix plants that have silica fume silos, based on a research update by the University of Calgary and Syncrude Canada that shows extracted MK from the tailings ponds performs comparably to SF in concrete strength gain. Substitution of SF with extracted MK, could result in savings in the order of $500/tonne or $50,000/year for a plant that supplies 100 tonnes/year of SF in concrete. If the existing SF silo could be utilized for the MK, no additional capital would be required

b. Demand

Estimates of demand for extracted MK that can be economically justified by ready mix plants in ternary blends are based on the following assumptions:

1. Consumption of concrete in Western Canada is in the order of 5 million m^3/year.

2. The percentage of concrete in this market that has compressive strength requirements of 30 MPa or greater is in the range of 25-30% or 1.25 to 1.5 million m^3/year.

3. A 5% PC substitution by MK in ternary blends with FA results in a consumption of 16 kg MK/m^3 of concrete. This results in a demand for extracted MK in this market sector of 20-24,000 tonnes/year. Demand for MK resulting from displacement of SF is very small and is not material to this analysis, other than the economic impact to the ready mix supplier.

Total demand estimates of extracted MK in Western Canada are less than the plant capacities used in this analysis. Therefore, additional markets would have to be found in the contiguous US states of Montana, Idaho, Washington and Oregon where transportation costs would be comparable to those used in this estimate. Given similar economics for ready mix suppliers in these regions, and a larger population base than that of Western Canada, the Northwestern US market is of fundamental importance to the justification of an oil sands extraction plant.

c. Metakaolin Demand Curve

Two of the points on the MK demand curve are now defined; at the current price of $680/tonne, demand for MK in Western Canada is virtually zero; at a price level of about $300/tonne, demand is in the range of 20-24,000 tonnes/year as defined in the previous section.

A number of respondents indicated that MK would have to be priced at a similar level to PC in order to offer significant economic benefits to ready mix suppliers. The basis for projecting MK demand when priced at $130/tonne is as follows:

1. Approximately 90% of concrete in Western Canada contains FA. FA typically ranges from 20-25% PC replacement when used in concrete.

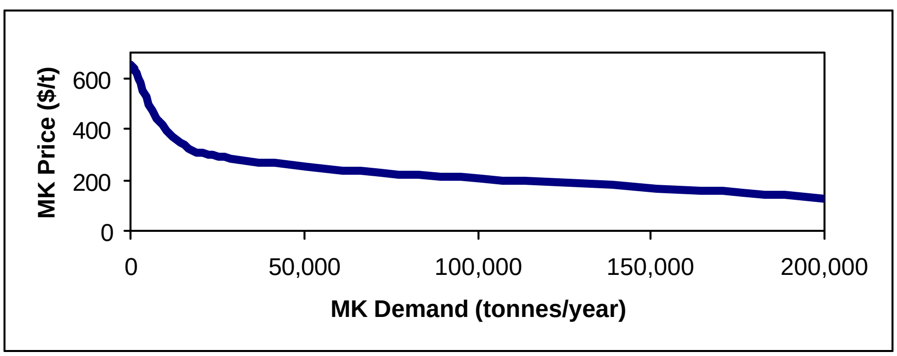
2. Ready mix suppliers will be motivated at these price levels to increase their use of MK to as high a level as possible which does not displace FA and improves the strength properties of the concrete such that at least some reduction in total CM is possible

3. J. Bai et al [32], explored the effects of various ternary blends of PC-MK-FA on the compressive strength of concrete. Their research indicated that the long term strength of concrete declined as FA replacement of PC approached 40%. This was offset by the addition of MK up to a maximum of 15% replacement of PC. Therefore, concrete suppliers should be able to reduce their batch costs for most end-uses with a ternary blend of 60% PC, 25% FA and 15%MK, with MK priced at $130/tonne.

4. Based on a 5 million m^3/year concrete market in Western Canada, of which 4.5 million m^3 contains FA, at 15% PC replacement, (assume 300 kg PC/m^3 of concrete) the demand for MK would be approximately 200,000 tonnes/year.

Based on these three demand/price points, a MK demand curve can be drawn as follows:

Figure 2.01
MK Demand Curve



It can be seen that the demand for MK increases almost exponentially as its price level approaches that of PC. Therefore, the potential for exploring economies of scale that allow reduced costs for MK are significant.

2.07 Conclusions and Recommendations

Following are the key conclusions drawn from the market research and analysis:

a. Based on the assumptions presented in this analysis, there is an economic benefit to ready mix suppliers by using extracted MK priced in the range of $280-$300/tonne in ternary blends with FA, for concretes with adequate strength levels to enable a 10% reduction in total CM.

b. Demand in Western Canada and the Northwestern US for MK at these price levels is adequate to justify an extraction plant with capacities in the range of 30-40,000 tonnes/year.

On a very preliminary basis, this study indicates there may be economic benefits to ready mix suppliers by using MK in ternary blends only if it enabled a 10% reduction in total CM for the same strength levels. In order to provide credibility to these assumptions, we recommend that tests be done that assess the economic efficiency of ternary, iso-strength blends with various levels of cementitious materials and FA/MK/PC ratios. Confirmation of greater than a 10% reduction in CM with a 5% MK replacement may justify additional trial and plant feasibility analysis. However, if the reduction in CM is less than 10%, additional work on this issue may not be justified.

3.00 COSTS

3.01 Capital Cost and Investment

A capital cost was prepared by Tynebridge in 1998 for a plant capable of producing 22,000 tonnes/year of MK during 5,000 operating hours. Tynebridge estimated the capital cost to be $30.6 million for a design-build contract plus $1.25 million for the owner's project costs giving a total installed cost of about $32 million.

NLK has prepared a feasibility grade estimate of the capital cost (see Appendix 2) using the equipment proposed by Tynebridge, inflating the costs for major equipment and using NLK's experience and database to estimate construction and indirect costs. We have assumed that the plant could be built near the Syncrude extraction operation so some of the existing services could be accessed. This may require taking the tailings from a "hot" effluent stream instead of from the tailings pond. Using this basis, we estimate the installed capital cost for the size of plant estimated by Tynebridge to be $24.3 million. We assumed that this plant would operate 8,400 hours/year to give a production capacity of 37,000 tonnes. The first three years of operation would be at reduced rates as the operators learned the operation and markets were developed.

We also considered a larger scale plant that would reduce the unit fixed operating costs. We have assumed that a plant that is double the size of the previously estimated plant would cost 1.8 times as much. By doubling the equipment size operating the plant 8,400 hours/year, the plant capacity becomes 74,000 tonnes/year. The feasibility grade installed capital cost is estimated to be $43.7 million.

Finally, we gave brief consideration to a much larger plant that would be capable of extracting kaolin from all of the tailings from an oil sands operation. This plant would use the same type of equipment proposed by Tynebridge to separate and possibly dry the bitumen, kaolin and sand. It would, however, use a rotary kiln for calcining similar to the cement industry. This plant would be ultimately capable of producing about 1 million tonnes/year of MK, which is comparable to the production of each of the cement kilns in Greater Vancouver. The cost of a one million tonne/year plant could be in the range of $200 to $240 million. However, if existing cement kiln capacity could be utilized by campaigning cement and MK, then the cost of a kiln and its related infrastructure could be avoided. This might reduce the capital requirement to the $140 to $170 million level. Capital costs may be significantly offset by credits for bitumen recovery, reduced effluent treatments costs and reduced fresh water consumption for the oil sands plants. In addition, the oil sands plants may be able to possibly avoid capital costs in other areas. The project could be installed in phases by installing single separation and drying lines initially, then installing additional lines as markets developed.

3.02 Production Costs

The Tynebridge study calculated a production cost of $167/tonne of metakaolin. This was based on an annual production of 22,000 tonnes. The following table is based on the data from the Tynebridge report.

Table 3.01
Tynebridge Operating Costs (1998)
22,000 tonnes/year

Item	Quantity	Unit	$/Unit	$/year	$/tonne
Manpower	22		$120,000	$2,600,000	$118.18
Reagents	12.863	kg/t MK	$200	$56,680	$2.58
Natural Gas	6.115	GJ/t MK	$2.00	$269,069	$12.23
Power	6158.86	kW/t MK	$0.044	$153,780	$6.99
Maintenance	8%	Equipment	$7,530,325	$602,426	$27.38
Total				$3,681,956	$167.36

NLK estimated the operating costs for a 37,000 tonne/year plant and a 74,000 tonne/year plant. NLK believes that the same number of people used in the Tynebridge study could operate the 74,000 tonne/year plant. We have assumed the same reagent use per tonne of MK and inflated the unit cost. For natural gas use, we have taken credit for the heat value of the bitumen remaining with the kaolin. In addition, we have taken credit for 90% of the heat in the exhaust gases from the calciner and used this heat in the dryer. This reduces fuel demand from 6.12 GJ/tonne MK (used by Tynebridge) to 3.26 GJ/tonne MK. We have assumed that power use and unit cost is unchanged. We believe that a maintenance cost of 8% of equipment cost is excessive. We have allowed 5.5%, which includes major maintenance costs and maintenance of business capital. The operating costs estimated by NLK when operating at maximum capacity are shown in the following tables.

Table 3.02
NLK Operating Costs (2002)
37,000 tonnes/year

Item	Quantity	Unit	$/Unit	$/year	$/tonne
Manpower	22		$130,320	$2,867,000	$77.49
Reagents	12.863	kg/t MK	$0.217	$103,300	$2.79
Natural Gas	3.26	GJ/t MK	$3.40	$428,500	$11.59
Power	158.86	kW/t MK	$0.044	$258,350	$6.99
Maintenance	5.5%	Equipment	$16,827,200	$578,450	$15.63
Total				$4,235,600	$114.50

Table 3.03
NLK Operating Costs (2002)
74,000 tonnes/year

Item	Quantity	Unit	$/Unit	$/year	$/tonne
Manpower	22		$130,320	$2,867,000	$38.74
Reagents	12.863	kg/t MK	$0.217	$206,600	$2.79
Natural Gas	3.26	GJ/t MK	$3.40	$858,000	$11.59
Power	158.86	kW/t MK	$0.044	$517,200	$6.99
Maintenance	5.5%	Equipment	$16,827,200	$925,500	$12.51
Total				$5,373,800	$72.63

The increased plant size lowers the operating costs by about $42/tonne MK.

No credit has been taken for the bitumen that is recovered, however this bitumen has a value of about $5/barrel or $31/tonne. Tynebridge estimates that the bitumen recovery would be 0.2 tonnes/tonne MK, which amounts to $6.34/tonne MK. For a 37,000 tonnes/year plant, the additional annual revenue would be $234,600, and for a 74,000 tonne/year plant increased revenue would be $469,200. This revenue could be used to offset the cost of services supplied by the oil sands operator.

The following table shows potential costs of a 1 million tonne/year plant assuming that the material, energy and maintenance costs are proportional to the smaller plants. Labour requirements and maintenance costs would increase proportionally less than production.

Table 3.04
NLK Estimated Operating Costs (2002)
1,000,000 tonnes/year

Item	Quantity	Unit	Separation $/t	Drying $/t	Calcining $/t	Total $/t
Manpower	29		$1.04	$1.69	$1.04	$3.78
Reagents	12.863	Kg/t MK	$2.79	$0.00	$0.00	$2.79
Natural Gas	3.26	GJ/t MK	$0.00	$5.54	$5.54	$11.08
Power	158.86	KW/t MK	$4.89	$1.05	$1.05	$6.99
Maintenance	4.0%	Equipment	$1.70	$1.06	$1.49	$4.25
Total			$10.43	$9.35	$9.12	$28.89

3.03 Transportation Costs

Because of the remote location of the oil sands, transportation costs for MK are a very significant portion of the total delivered cost. Transportation to the consuming cities would be by rail then trucks would be required for distribution to individual ready mix plants.

For the 37,000 tonne/year plant, NLK has allowed $90/tonne MK comprising $60 per average rail cost and $30/tonne local distribution costs. A 74,000 tonne/year plant would require a much larger market area, possibly extending south into California. We have allowed a total of $120/tonne MK for this option.

Depending on the level of replacement of PC by MK, the market area could be higher or lower. This would result in higher or lower transportation costs.

Because the transportation costs are such are large portion of the total costs, and because the market area for a 74,000 tonne/year plant is no doubt much larger than for a 37,000 tonne/year plant, the economic benefit of reducing operating costs by increasing the plant size diluted. However, for the very large plant, it may be possible to arrange dedicated transportation for large volumes such as unit trains and coastal barges, which may lower transportation costs.

3.04 Cash Flow Analysis

a. 37,000 Tonne/Year Plant

The cash flow analysis is shown in Appendix 3. We have assumed that the plant would operate at reduced capacities of 50, 70 and 90% for the first three years of operation and achieve 100% capacity during subsequent years.

For a capital cost of $24.3 million, operating cost of $114.50/tonne MK at 100% operating rate and $90/tonne MK freight cost, a selling price of $303/tonne MK results in an internal rate of return of 10%.

If the $6.34/tonne MK bitumen credit is taken, the return improves to 11%.

b. 74,000 Tonne/Year Plant

The cash flow analysis is shown in Appendix 3. We have assumed that the plant would operate at reduced capacities of 40, 60 and 80% for the first three years of operation and achieve 100% capacity during subsequent years. The rates assumed are lower than for the 37,000 tonne/year plant because we anticipate more time will be required to develop a market for the entire production.

For a capital cost of $43.7 million, operating cost of $72.63/tonne MK at 100% operating rate and $120/tonne MK freight cost, a selling price of $282/tonne MK results in an internal rate of return of 10%.

If the $6.34/tonne MK bitumen credit is taken, the return improves to 11%.

c. Very Large Plant

The potential of offsetting enough of the capital for a large plant and lowering transportation costs should be explored. This may enable a delivered cost of MK in the range of PC and provide a reasonable return on capital employed.

4.00 TECHNICAL

4.01 Metakaolin Production

a. Kaolin Extraction Technology

Kaolin is a naturally occurring substance formed by the erosion of the earth's surface. It has been used for centuries to produce ceramics and more recently it has found use as a pigment for use in paint and paper. In fact, the greatest demand for kaolin in North America comes from the paper industry for coating and filling of papers and boards. This application demands a clean, white material to enhance paper brightness and printing qualities.

The deposits containing kaolin also contain sand, which must be removed. Kaolin particles are very small compared with the sand particles so they settle at different rates. To separate the kaolin, the kaolin/sand mixture is normally mixed with water and chemical dispersants then sent to gravity thickeners. The sand-rich stream is removed from the bottom while the kaolin-rich stream is removed from the top. For papermaking applications, the brightness of the kaolin can be further enhanced by one or more processes including bleaching, magnetic separation, flocculation, ozonation, floatation and oxidation, which will remove iron, titanium, organic and other undesirable materials. Large rotary vacuum filters then remove water from the slurried kaolin, and gas-fired spray dyers remove and evaporate the remaining moisture. [1]

The extraction of kaolin from the oil sands tailings should be able to utilize much of the same technology. The main differences are: the tailings contain residual bitumen and enhanced brightness is not required for the concrete industry.

In 1998, Syncrude retained Tynebridge Technologies Limited to develop a workable process and prepare a capital cost estimate. For the purposes of this report, the extraction process presented in the Tynebridge study [2] is assumed to be technically viable. The Tynebridge process begins by pumping mature fine tailings, mixed with sodium silicate, to attrition cells. From the attrition cells, the product would flow to a primary clarifier where bitumen would be floated off. The bitumen would flow to a tank prior to being pumped back to extraction, while the clarifier underflow, including a mixture of kaolin and silt, would be pumped to a secondary thickener.

Silt, being heavier than kaolin and bitumen, would settle preferentially in the thickener, be removed as underflow and be returned to the tailings ponds. The thickener overflow containing mostly kaolin, with some bitumen, would flow to the thickener overflow tank. This tank would operate at a set level with an overflow to the bitumen return tank. The remainder of the thickener overflow would be pumped to a drum filter for dewatering. The study suggested a possible alternate arrangement using New Logic's V*Sep filters to recover the bitumen, but indicated that this would require more investigation.

The drum filter would produce a wet filter cake (50% solids) that would be pumped to a spray dryer. The study indicated that off gas from the calciner would be used as the heating medium in the dryer, but the economics included the cost of gas to provide heat. The study states that dried clay, surface dry but still containing water of hydration, is reported free flowing so it would be conveyed to a multiple hearth calciner. The calcined clay, also known as metakaolin, should be free flowing, but a hammer mill would be provided in case of agglomeration.

b. Metakaolin Production Technology

Kaolinite, the most common constituent of kaolin, is hydrated aluminium disilicate, $Al_2Si_2O_5(OH)_4$. Metakaolin (MK) is formed by heating kaolinite in a controlled manner to drive off the water of hydration. This change, called dehydroxylization, occurs in the temperature range of 500-800^oC. This process of thermal activation, also referred to as calcining, results in metakaolin, which is highly pozzolanic.

The affect of the calcining process on the metakaolin properties has been studied by several investigators. The following is an excerpt from B.B. Sabir et al. [3] who presented a summary of the findings.

"The burning or calcining temperature of clay affects the pozzolanic reactivity of the resulting product. The clay is in its most reactive state when the calcining temperature leads to loss of hydroxyls and results in a collapsed and disarranged clay structure. The calcining temperature producing the active state is usually in the range 600-800^oC [4]. Ambroise et al. [5] determined the effect of the calcining temperature of kaolinite (600-800^oC) on the strength development of 1:1 MK-lime pastes of water:solids ratio 0.72, at different curing times. The optimum calcining temperature, to give maximum strength at 3, 7, and 28 days was 700^oC. In another paper, Ambroise et al. [6] showed that calcinations below 700^oC results in less reactive metakaolinite with more residual kaolinite. Above 850^oC crystallisation occurs and reactivity declines. Marvan et al. [7] have shown that on calcination at 800^oC kaolinite and gibbsite present in lateritic soils are transformed into transition phases of MK and amorphous alumina. If clays are heated at even higher calcining temperatures liquid phase forms which on cooling solidifies into an amorphous glass phase. Amorphous glass also shows pozzolanic activity as in the case of FA (fly ash), which are normally composed of 70-90% glass phase.

Kaolinites are usually calcined in rotary kilns or using fluidised bed processes which allows the reduction of calcining time from hours to minutes. Salvador and Davies [8,9] used flash-calcination to reduce the calcining time to seconds. The process consists of rapid heating, calcining and cooling. The authors showed that different qualities of MK are obtained depending on the temperature (500-1000^oC) and time of flash-calcination (0.5-12s) and that more active MK can be produced by this method, than by soaking."

The equipment proposed by Tynebridge is a Hankin multiple hearth calciner supplied by IMPEX [10], which is a vertical furnace comprising alternating in and out hearths. The number of hearths is determined by the desired production rate and process requirements for time and temperature. Material is moved through the unit by rabble teeth, or plows, driven from a central (vertical) shaft.

c. Production Capacity

The tailings reportedly contain about 10% clay. Of this, about 20% could be converted to metakaolin. If one million tonnes of tailings are extracted daily in the bitumen recovery process, then the total annual metakaolin potential is about six million tonnes.

The size of plant costed by Tynebridge was 22,000 tonnes/year based on a 5,000 hours/year operation. This capacity utilized the smallest readily available equipment. If the plant were operated 8,400 hours/year, the capacity would be 37,000 tonnes.

In order to reduce the fixed costs per tonne, NLK considered doubling the size of the plant to 74,000 tonnes/year. We assumed that the same number of people could operate a plant of this size.

Even at the higher capacity the kaolin in the oil sand tailings would only be reduced by a very small percentage. An extraction plant with a capacity in the order of 1 million tonnes/year would be required to have a significant impact on reducing the colloidal material in the oil sands tailings.

Process concepts should be developed for a very large extraction plant. The design should allow incremental installation and start-up of the facility to enable gradual phase-in of the plant's capacity.

d. Current Availability of the Technology

Metakaolin, or calcined clay, is presently produced from mined kaolin. Its largest uses are as a filler in the paper industry and a pigment in the paint industry. The North American production comes from the south east of the United States, mainly Georgia. The kaolin/sand mixture is slurried in water then the slurry is passed to a clarifier. Here the faster settling sand particles sink preferentially to the bottom where they are removed while the smaller kaolin particles are removed from the top. The same technology can be used for the tailings expect an intermediate floatation step can be inserted to recover some of the residual bitumen.

After the kaolin is separated from the sand, it can be dried and calcined using proven equipment. The equipment chosen by Tynebridge is a cylindrical dryer followed by a five-hearth furnace.

e. Technological Issues

The chemical composition of Type I Portland cement, metakaolin [11], mineral ash from the Tynebridge study and treated kaolin in oil sands tailings [12] is shown in the following table.

Table 4.01
Chemical Analysis (%)

Component	Type I PC [11]	MK (1) [11]	Mineral Ash (2)	Treated MFT (3)
Silicon dioxide (SiO_2)	20.1	51.34	57.27	57
Aluminum oxide (Al_2O_3)	4.51	41.95	30.90	38
Ferric oxide (Fe_2O_3)	2.50	1.52	4.10	1.4 (4)
Calcium oxide (CaO)	61.3	0.34	0.41	
Magnesium oxide (MgO)	3.13	0.03	1.32	0.7
Sodium oxide (Na_2O)	0.24	0.34	1.63	0.7
Potassium oxide (K_2O)	0.39	0.11	3.07	2.0
Phosphorous oxide (P_2O_5)	<0.9	0.28	0.09	
Titanium oxide (TiO_2)	0.24	1.74	1.17	0.9
Sulphur trioxide (SO_3)	4.04	0.07	0.10	
Loss on Ignition	2.41	0.72		

Note:
1. Typical mined MK analysis
2. Mineral ash of mid clay sample of untreated MFT from Batch #2 of Tynebridge pilot study [2]
3. In a laboratory study by CANMET AST, MFT (Mature Fine Tailings) were centrifuged and bleached to reduce impurities [12]
4. As FeO

It can be seen that the impurity levels of the mineral ash from the mid clay fraction are not significantly different from those in Portland cement or metakaolin produced from mined kaolin. As a result, the material produced from the oil sands tailings should be usable in concrete in a manner similar to metakaolin produced from mined kaolin.

The last column is included to show that the amorphous oxides of aluminium, silicon magnesium and iron could be dissolved using an oxalic acid treatment and residual iron compounds could be dissolved with a citrate-bicarbonate-dithionate treatment. These purification steps were conducted to determine the effect for possible papermaking applications. Although the procedure did remove some impurities and improve brightness, the end product was still not white enough for use as a papermaking additive. The addition purification steps have not been included in the metakaolin process economics.

f. Other Examples

MK is produced in the south eastern USA by companies like Engelhard who markets MetaMax® and IMERYS who markets MetaStar®. In Brazil the kaolin deposits are similar to those in Georgia, and IMERYS plans to double its current kaolin production and introduce new calcined kaolin products for paint applications. In India, 20 Micron Ltd. and The Indian Aluminum Co. Ltd. both added capacity to their calcined kaolin operations in 1998 and 1999. Attempts are currently underway to finance a calcined kaolin operation in Australia. In the United Kingdom, RMC Ready-Mix will supply concrete mixes containing MK.

There is currently no MK produced from kaolin recovered from oil sands tailings.

4.02 Metakaolin as a SCM

a. Performance

Metakaolin is a pozzolan, which is defined as "a siliceous and aluminous material which in itself possesses little or no cementing property, but will in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties." [13]

B.B. Sabir et al. [3] report that MK as a pozzolanic addition acts to remove calcium hydroxide (CH), which is produced by the hydration of cement. MK contains silica and alumina in an active form that will react with CH. By removing the CH, concrete durability is improved. This improved durability also occurs when using other pozzolans like SF and very fine FA.

CH removal has a major influence on resistance to sulphate attack and alkali silica reaction (ASR). It also provides enhanced strength because of the additional cementitious compounds generated by the reaction of CH with MK. Very early strength enhancement is due to a combination of the filler effect and accelerated cement hydration [14].

Sabir reports [3] that it is universally accepted that the principal cementitious reaction for a pozzolan is facilitated by the dissolution of the silica in the pore water. The silica then reacts with the CH to form a calcium-silicate-hydrate (CSH) gel. Alumina also dissolves and the bulk of it reacts to form calcium-aluminate-hydrate (CAH) and calcium-aluminate-silicate-hydrate (CASH) phases, which may assist in the cementitious process and contribute to strength. The dissolution rate depends on the specific surface. SF and MK have high specific surface areas relative to PC, while FA has a low specific surface area. As a result, when SF and MK are used as partial replacement for PC, they develop strength faster than the PC concrete; whereas, when FA is used the strength development is slower than the PC concrete.

The high surface area of MK also increases water demand. Therefore, for a given w/b ratio and cement content, the workability of the MK concrete is lower relative to PC concrete. The amount of reduction is apparently less than that for SF concrete. In contrast, FA actually improves workability because of its spherical nature and because of the adherence of the very fine FA particles onto the PC grains which improves dispersal.

b. Current research and knowledge

B.B. Sabir et al. [3] recently reviewed the work done on the use of MK as a partial pozzolanic replacement for Portland cement (PC) in mortar and concrete. The following information is from that report.

Wild and Khatib [15] showed that the partial replacement of PC by MK resulted in increased strength. The optimum strength improvement was seen with about 10% replacement. The increase was particularly evident during the early days of curing with a peak strength improvement at about 14 days. After that time the strength enhancement decreased, but always remained above the control PC concrete in the mortars examined. Wild et al. [16] also showed that increasing the specific surface of MK reduced the age at which maximum strength occurs but did not influence the long term (90 day) strength.

Curio et al. [17] tested mortars at 15% replacement of PC with MK and silica fume (SF). They found that their superplasticized mortars (water-to-cementing materials ratio=0.33) gave compressive strengths similar to, and in some cases, greater than SF mixtures.

Kostuch et al. [18], Bredy et al. [19] and Khatib and Wild [20] all studied the influence of MK on the microstructure and diffusion properties of blended cement pastes and concrete. In [18] significant reductions in average pore size were shown at 20% PC replacement. It was also found that MK is effective at reducing the rate of diffusion of Cl^- and Na^+ ions in mortar and in reducing the rate of water absorption. In [19] it was suggested that a hydrated blended cement with 30% replacement with MK could be more durable under freezing and thawing conditions due to small pore size. In [20] it was found that, for pastes containing up to 15% MK, the proportion of the pores of radii less than 0.02 microns increased with both MK content and curing time.

Several studies have demonstrated clearly that strength enhancement, particularly at the early stages of curing, can be realized. Caldarone et al. [21] produced concretes with 5% and 10% MK that exhibited slightly greater strengths than concretes containing the same levels of SF. Wild et al. [14] report similar influences of MK on concrete strength. The authors identify three elementary factors that influence the contribution the MK makes to concrete strength. These are the filler effect, which is immediate, the acceleration of PC hydration, occurring within the first 24 hours and the pozzolanic reaction that reaches its maximum within the first 7-14 days. Little strength advantage was observed for MK levels in excess of 15%.

Sabir [22] studied the effect of curing temperature on strength. Strength at 7 days was higher when curing up to 15% MK concrete at 50°C compared with 20°C, however, this benefit diminished with time. The optimum MK replacement was10% at 20°C with w/b=0.35. This level decreased to 5% MK for concretes cured at 50°C with w/b=0.45.

Brooks et al. [23] showed that, as with SF and FA, MK retards setting time for high-strength concrete. In general, increasing pozzolan levels increased setting time, however, for MK this increase was only observed up to a 10% replacement level.

Walters et al. [24] determined that MK suppresses ASR in concrete. The expansion was reduced from 0.45% to 0.01% after 6-9 months when MK replaced 10-15% of the PC. It was also reported that the cracks and surface deterioration present in the PC concrete were virtually eliminated.

Marwan et al. [7] calcined lateritic soil to convert the kaolinite present to MK and found that using this admixture resulted in enhanced concrete performance when exposed to sea water and acidic solutions. Bosc et al. [25] also found that MK blended mortars showed improved durability when exposed to sea water.

Khatib and Wild [26] studied the effect of sulphates on concrete and concluded that at least 15% replacement of PC with MK was required to provide good sulphate resistance. Martin [27] used 15% MK to reduce the mass loss of the concrete by 30% when exposed to aggressive organic acids from silage effluents. In addition, Pera et al. [28] showed that the presence of 10% MK limited damage caused by lactic acid. However, while MK was more pozzolanic than SF, it was less effective at reducing loss in an ammonium sulphate solution.

Although it is generally acknowledged that MK adversely affects concrete workability, no detailed examinations have been reported concerning the water demand of MK and its influence on the concrete flow properties. Caldarone et al.[21] observed that the MK concrete required 25-35% less high range water reducers than equivalent SF mixtures. This resulted in a less sticky consistency and better finish for the MK concrete compared with the SF concrete. Wild et al. [14] employed 3% superplasticizer to produce moderate slumps (75 mm) in MK concrete with a w/b ratio of 0.45.

A research update on "Potential Use of Metakaolin from oil sand tailing in Concrete" [29] compared the performance of concrete containing SF, MK and calcined tailings at PC replacement levels up to 15%. This work indicated that the pure MK performance was better than SF, while the performance of the MK from oil sand tailings was about 85-90% of the pure MK and slightly less than SF. The study suggested the need to conduct longer tests, extend tests to reinforced and prestressed concrete, conduct structural mineral analysis, determine the optimal calcining temperature and improve quality control.

c. Current Use in Concrete Technology

MK use is mainly as an alternative to silica fume for use in concrete requiring specific properties. There was a case reported [3], however, where about 300,000 tonnes of locally calcined clay were blended with more costly imported PC to construct a reservoir in the Amazon basin during the 1960's.

MK can be used to replace or add to PC or can be combined with other pozzolans. The proper use of MK can result in increased concrete strength (particularly early strength), improved chloride and sulphate resistance, reduced efflorescence, and improved durability.

MK has an inherent advantage over SF because MK is white and SF is a dark colour. This permits colour matching with existing concrete when using MK. In addition, the brighter colour imparted to the concrete by MK could improve the night driving visibility if MK concrete were used in highway and bridge construction and would improve the appearance of exposed concrete.

d. Previous Experience in Cement Industry

Metakaolin use in the concrete industry is very limited. It is commercially available as MetaMax®, which is produced in Georgia, USA by Engelhard Corporation. Metakaolin is also marketed by Advanced Cement Technologies (ACT) under the name PowerPozz™, but the product is sourced from the south east USA. There was a source of MK in California, but this is no longer available.

Metakaolin is approved for use by the New York, Illinois, Florida and California Departments of Transportation. When the specification was changed in New York to allow the use of MK as a replacement for SF, a few producers used the product for bridge deck construction. The producers indicated that MK worked as well as SF with respect to performance; however, batching and handling was somewhat more difficult. They also indicated that MK was cohesive and packed in a storage silo much like cement so vibrators were necessary.

Milburn Cement in New Zealand reported [30] in 1998 that Hi Stress Concrete Ltd. had opted to use MK in its mix for high durability concrete piles. In tidal situations, the objective was to inhibit the ingress of chloride ions, which can depassivate steel reinforcing. Hi Stress felt that MK and SF have similar effectiveness when used at the 10% PC replacement level. They chose MetaMax® because they felt that, in addition to greatly enhanced chemical and physical properties, the fresh concrete had a cohesive "creaminess". This allowed placement at higher plasticity and less compactive effort compared with SF concrete.

We are not aware of any MK use in concrete in Canada.

e. Advantages of Using Metakaolin

Improved durability of the concrete is the main advantage of using MK. The small size and the pozzolanic nature of the MK particles results in removal of CH produced by the hydration of PC and the creation of stronger cementitious materials. As a result, the concrete is not only stronger, but more dense. The higher density improves chloride and sulphate resistance. Removal of the CH also suppresses ASR, which reduces concrete expansion, spalling and efflorescence.

The use of MK will reduce the amount of PC required. Because the chemical conversion of calcium carbonate, the main component of PC, releases carbon dioxide, whereas the conversion of kaolinite to MK releases no carbon dioxide, there will be a decrease in the amount of GHG produced in concrete production. The calcining temperature required to produce MK is also lower than that required to produce PC so less fuel is required. This also has a positive impact on GHG emissions. The positive impacts are slightly reduced by the need to transport the MK farther.

f. Challenges of Using Metakaolin

Because MK is much finer than PC and is planar rather than spherical, it requires more water to form a fluid mixture when making concrete. Although the increased requirement is apparently less than that for SF, it is significant. In order to minimize the water requirement, and thereby maximize the strength of the final concrete, superplasticizers are required. These are also required with SF, but are not normally used with FA at common usage levels. Because of the spherical shape of FA, its use actually reduces the water requirement compared with PC.

Ready mix concrete producers typically deal with two or three cementitious materials (CM's), namely PC, FA and SF. MK use would introduce an additional CM, which would add another variable to the concrete recipe and probably require an addition silo. There would have to be an economic advantage offered by MK in order for the Ready mix producer to consider its use.

The delivered cost of MK compared with PC and FA makes economic justification difficult. MK could be used to replace SF in high strength concretes; however, this market is very small. It might also find use in autoclave concrete and cement board. If it were possible to reduce the total cementitious component of concrete by the use of a ternary blend of MK, FA and PC, there may be some justification. If this possibility exists, it is probably restricted to the greater than 30 MPa concretes. In order for MK to be considered for use in a wide range of concrete applications, its delivered cost must approach that of PC.

5.00 ENVIRONMENTAL IMPLICATIONS OF METAKAOLIN PRODUCTION FROM TAILINGS PONDS MATURE FINE TAILINGS (MFT)

5.01 Introduction

As part of the development of an air quality management plan for the Lower Mainland and the Fraser Valley, the GVRD is investigating options to reduce the emissions of greenhouse gases (GHG's). Some GHG's occur in nature, while others are a result of anthropogenic (human) activities. Naturally occurring gases include water vapour, carbon dioxide, methane and ozone. Human activities, however, add to the levels of these naturally occurring gases:

a. Carbon Dioxide: Released to atmosphere through the combustion of solid waste, fossil fuels, and wood and wood products

b. Methane: Emitted through the production and transport of fossil fuels, decomposition of organic matter in landfills and through the raising of livestock

c. Nitrous Oxide: Generated during agricultural and industrial activities, as well as the combustion of fossil fuels

Very powerful greenhouse gases that do not occur naturally include hydrofluorocarbons (HFC's), perflurocarbons (PFC's) and sulphur hexafluoride (SF_6).

Each GHG differs in its ability to absorb heat in the atmosphere, with HFC's and PFC's being the most heat-absorbent. Estimates of GHG emissions are usually expressed in units of 'carbon dioxide equivalents', which rates each gas by its Global Warming Potential (GWP), with CO_2 assigned a value of 1. For example, methane traps 21 times more heat per molecule than CO_2, while nitrous oxide traps 270 times more heat per molecule as compared to CO_2.

Canada's third national report on climate change [40] identified CO_2 as the prevalent GHG, at about 78% of the total, followed by CH_4 at 13% and N_2O at 8%, based on carbon dioxide equivalents. The most prevalent sector was energy, representing about 80% of the emissions, followed by agriculture at 9% and industrial processes at 7%.

For the industrial processes sector, CO_2 comprised 78% of the GHG's, followed by PFC's at 12%. The 'Non Metallic Mineral' category under the industrial process sector would include manufacture of cement. GHG's from this category represent 22% of the sector and about 1% of the national GHG emissions. The GHG signature for the 'Non Metallic Mineral' category is essentially all CO_2, with minor contributions from other GHG gases.

As part of the development of an Air quality Management Plan for the Lower Mainland and the Fraser Valley, the GVRD is looking at options to reduce GHG emissions. From the GVRD 2000 Emissions Inventory [37], GHG gases totalled about 17.4 million tonnes as CO_2 equivalents, with contributions from point, area and mobile sources. Non Metallic Minerals, which essentially represents the cement manufacturing sector, comprised some 11% of the total GHG emissions, at about 1.9 million tonnes/year.

The two cement plants in the lower mainland are Lehigh Cement and Canada Lafarge.

Cement manufacture is an energy and raw material intensive process resulting in the generation of CO_2 from both the energy consumed in making the concrete and the chemical process itself. The production of one tonne of cement generates about 0.9 tonnes of CO_2 [36]. Options to reduce the GHG signature of cement include energy optimization (oil and natural gas generate less GHG than coal), energy recovery and reuse in the manufacturing process, changes to the production process itself and the level of fillers used in clinker manufacture. These and other options are being considered and introduced by the industry.

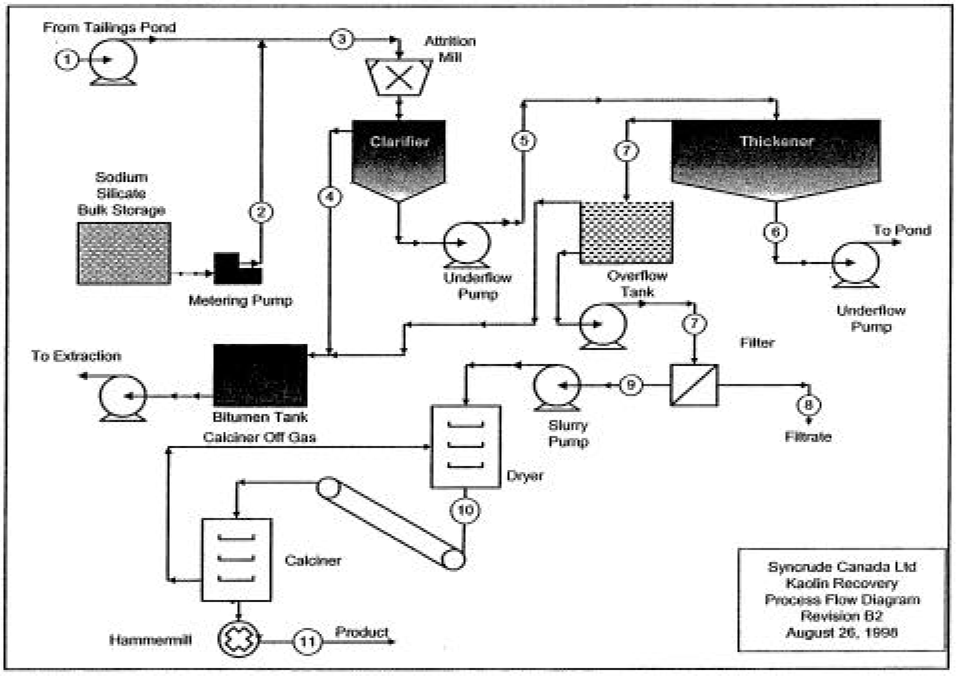
The amount of cement used in concrete varies with mix composition and desired end properties and usually represents about 10 - 15% by weight. A typical composition for concrete would include about 12% cement, 34% sand, 48% aggregates and 6% water. About 90% of the GHG signature of concrete is attributable to the cement component.

Another approach to reduce the GHG contribution from concrete is by replacing part of the cement with supplementary cementitious materials (SCM's). These can include: fly ash, steel blast furnace slag, silica fume, clay, metakaolin, pumice, rice hulk ash and Cominco ground slag. Fly ash (from coal fired generating stations) is the most widely used SCM in the industry. Maximum replacement of cement is property dependent, but is typically about 25-30%. The reduction in the GHG signature of concrete is about 0.9% for each 1% decrease in cement content.

In the processing of oil sands by Syncrude, Suncor and others in NE Alberta, the clays separated in the bitumen extraction process are discharged with mill effluent to large settling ponds, where the fine clays gradually settle over time. The settled solids contain a significant amount of kaolin clays and are termed 'Mature Fine Tailings' or MFT. Metakaolin (MK) has been recognized as a SCM, with properties similar to silica fume. At the present time, MK is manufactured from kaolin mined predominantly in the SE United States.

Interest has been expressed in evaluating the potential for the manufacture of MK from the MFT's at oil sands processing plants. Tynebridge Technologies Limited (TTL) was retained by Syncrude to develop a preliminary design for a plant to produce MK from MFT's, with a flow diagram included as Figure 5.01. The economical manufacture of MK and its increased use in concrete would have the potential to decrease the CO_2 signature of concrete, as well as provide a means of reusing MFT's and reducing environmental challenges associated with long term storage and ultimate reclamation of the mine effluent and tailings.

Figure 5.01
Tynebridge Technologies Ltd.: MK Production Process [2]



5.02 Emissions to the Environment from the TTL Process

The following discussion on emissions from manufacture of MK is based on the preliminary process developed by TTL and shown in Figure 5.01. MFT's are pumped from the tailings pond to an attrition mill, followed by a clarifier to recover residual bitumen from the effluent. Separation efficiency for bitumen was estimated at about 90%, with the recovered material directed to the extraction process. The settled solids from the clarifier are thickened, with the underflow returned to the tailing pond. The accepts are directed to a drum filter, with the filtrate either returned to the ponds or considered for reuse in the extraction process, dependent on the level of residual suspended solids.

The slurry from the drum filter would be pumped to a spray dryer, where natural gas would be used to supplement energy in the calciner flue gas to achieve about 83% oven dry solids. The dryer discharge would be conveyed to a multiple hearth calciner (fired on natural gas) to remove the residual entrained water and the water of hydration from the kaolin, generating metakaolin as a final product. On a dry solids basis, this process was estimated to generate about 43% of the MFT's as MK.

Discharges from this process (based on a production level of 37,000 t/annum) would include the following.

a. Bitumen - estimated recovery at 90% (0.9 t/hour) and directed to the extraction process. Residual bitumen in the dried clay (0.09 t/hour) would represent a fuel source in the calciner, and is taken into account when estimating emissions to the atmosphere as well as requirements for natural gas.

b. Thickener underflow - this stream would be estimated to contain about 55% of the dry solids (5.6 t/hour) in the process feed and would be returned to the tailings pond.

c. Filtrate - dependent on the residual solids content, this flow could be reused within the extraction process or returned to the tailings pond. The flow would represent about 71% (16.6 m^3/hour) of the feed from the tailings pond.

d. Dryer vent to atmosphere - this stream would represent the most significant environmental impact of the manufacturing process and contain numerous contaminants, including GHG's, particulate, SO_2 and NO_x. Under normal operation, there would be no vent to atmosphere from the calciner. The flue gas from this source would be directed to the dryer to provide partial energy requirements.

The dryer vent would be equipped with a fabric filter (baghouse) to address particulate emissions and both the dryer and calciner with low NO_x burners to minimize oxides of nitrogen.

Water streams from the MK manufacturing process would be either returned to the tailings pond or reused in the extraction process, dependent on the suspended solids levels. There would be no meaningful solid waste stream that would require disposal. The most significant environmental impact of the production of MK would be emissions to atmosphere.

a. Emissions to Atmosphere

Gaseous emissions from the dryer were estimated for CO, NO_x, SO_2, three greenhouse gases - CO_2, N_2O and CH_4, and particulate matter based on a production of 37,000 tonnes/year of MK.

Emission estimates were developed for the gaseous pollutants based on the 'USEPA Compilation of Air Pollutant Emission Factors AP-42 (5th edition), Volume 1: Stationary Point and Area Sources' for: natural gas with low NO_x burners in both the dryer and calciner [35]; No. 6 fuel oil as a surrogate for residual bitumen in the feed to the calciner [34] and processing (drying, calcining) of kaolin clays [33]. Factors used and calculated emissions for the identified parameters are summarized in Table 5.01.

Table 5.01
Manufacture of MK - Emissions to Atmosphere [33,34,35]

PARAMETER	EMISSION FACTOR	EMISSIONS		
		t / t MK	t/ year	Total
CO_2	1,930,000 kg/10^6 Sm^3 gas	0.31	11,470	
	3,000,000 kg/10^3 m^3 fuel oil	0.06	2,220	13,690
CO	1,350 kg/10^6 Sm^3 gas	$1.2x10^{-4}$	4.4	
	600 kg/10^3 m^3 fuel oil	$1.3x10^{-5}$	0.48	4.9
NO_x	2,250 kg/10^6 Sm^3 gas	$2.0x10^{-4}$	7.4	
	5,640 kg/10^3 m^3 fuel oil	$1.2x10^{-4}$	4.4	11.8
N_2O	10.3 kg/10^6 Sm^3 gas	$9x10^{-7}$	0.033	
	63.6 kg/10^3 m^3 fuel oil	$1.3x10^{-6}$	0.048	0.081
SO_2	9.7 kg/10^6 Sm^3 gas	$8x10^{-7}$	0.03	
	684 kg/10^3 m^3 fuel oil	$1.4x10^{-5}$	0.52	0.55
CH_4	37 kg/10^6 Sm^3 gas	$3.2x10^{-6}$	0.12	
	33.6 kg/10^3 m^3 fuel oil	$7x10^{-7}$	0.025	0.15
PM (filterable)	0.019 kg/t MK	$1.9x10^{-5}$	0.73	0.73

Basis:

- Calciner and dryer fired on natural gas. Average emission estimates based on large boiler (heat input > 100 GJ/hour) with low NO_x burner.
- Average emission factors for residual bitumen in calciner feed based on # 6 fuel oil, normal firing (heat input > 100 GJ/hour).
- Calciner flue gas is directed to dryer and not vented independently under normal operation.
- The dryer is equipped with a fabric filter (baghouse).
- SO_2 content of pipeline natural gas used as 4.6 kg/10^6 Sm^3
- SO_2 content of #6 fuel oil used as 1% (w/w).
- Annual emissions based on a MK production of 37,000 t/year.

No allowance was included for emissions associated with processing of the bitumen recovered from the MK manufacturing process.

For the TTL process, fuel energy requirements were estimated as follows:

Calciner -	2.5 GJ/t MK
Dryer -	3.3 GJ/t MK
Total:	5.8 GJ/t MK
Residual bitumen to calciner (credit) -	0.8 GJ/t MK
Calciner flue gas to dryer (credit) -	1.7 GJ/t MK
Net fuel energy requirements:	3.3 GJ/t MK

Unit CO_2 emissions averaged 0.37 t/t MK produced (13,690 t/year), with 84% of the total attributable to natural gas. This was much higher than the other two GHG's, with N_2O at $22x10^{-7}$ t/t MK (0.081 t/year) and CH_4 at $39x10^{-7}$ t/t MK (0.15 t/year).

Unit emissions of other gaseous parameters were:

- CO - $13x10^{-5}$ t/t MK (4.9 t/year)
- NO_x - $32x10^{-5}$ t/t MK (11.8 t/year)
- SO_2 - $15x10^{-6}$ t/t MK (0.55 t/year)

The dryer vent would be equipped with a fabric filter or baghouse. Total filterable particulate emissions from this controlled source were estimated at 1.9x10-5 t/t MK (0.73 t/year). This estimate does not include any contribution from condensable particulate, which should be minor in this application. Fabric filters are efficient at removing fine particulate and are widely used in the manufacture and processing of cement and clays.

The PM 10 fraction of the filter discharge has been measured at 88% for a flash calciner on kaolin clays, followed by a baghouse, with PM2.5 at 55% [33]. Similar levels would be anticipated from a dryer equipped with a fabric filter. Tables 5.02 & 5.03 illustrate particulate emissions for a multiple hearth furnace and a flash calciner and reflects the effectiveness of a fabric filter on a calciner discharge.

Table 5.02
Particulate Emissions for Kaolin Processing [33]

Source		Filterable PM		
		PM (kg/t)	PM 10	
			kg/t	% of PM
Multiple Hearth Furnace	- uncontrolled	17	8	47
	- fabric filter	not tested	not tested	not tested
Flash Calciner	- uncontrolled	550	280	51
	- fabric filter	0.027	0.023	84

Table 5.03
Summary of Particle Size Data for Kaolin Processing [33]

	Cumulative Percent Less Than		
Particle Size (micron)	Multiple Hearth Furnace, Uncontrolled	Flash Calciner	
		Uncontrolled	With Fabric Filter
1.0	5.65	-	26.93
1.25	8.21	11.14	31.88
2.5	22.99	25.32	55.29
6.0	42.1	44.65	77.34
10	47.22	50.87	88.31
15	52.02	55.35	94.77
20	56.61	59.45	96.56

The uncontrolled emissions from a multiple hearth furnace averaged 17 kg/t, with the PM 10 fraction at 47%. For a flash calciner, uncontrolled emissions averaged 550 kg/t of product, with the PM 10 fraction at 51%. With the addition of a fabric filter, particulate emissions were reduced by more than 99% to 0.027 kg/t, with the PM10 fraction at 84%.

b. Comparison of Emissions: TTL Process and Other Area Sources

Table 5.04 compares estimates of air emissions from a metakaolin manufacturing facility for 37,000 t/year and 1,000,000 t/year, to reported emissions from Syncrude, Suncor and the Lower Mainland cement plants (Lehigh, Canada Lafarge). With a MK production facility located in Ft. McMurray, emissions for NO_x, SO_2 and PM are minor in relation to those from major oil sands processing facilities in the area. Carbon dioxide emissions for the 37,000 t/year facility, would represent 0.1% of combined CO_2 from Syncrude and Suncor and less than 1% of CO_2 emissions from the two cement manufacturing companies in the Lower Mainland. For the 1,000,000 t/year plant, CO_2 would represent about 3% of combined emissions from Syncrude and Suncor and 20% of that for cement manufacturing in the Lower Mainland.

Table: 5.04
Emissions to Atmosphere - Tonnes/Year [37,38,39]

SOURCE	CO_2	NO_X	SO_2	PM
Syncrude (2000)+	8,010,000	16,900	70,700	-
Suncor (2000)+	4,781,000	19,100	17,200	-
Lower Mainland Cement Plants (2000)	1,875,000	3,740	-	1,150
MK (1,000,000 tonnes/year)+	370,000	320	15	20
MK (37,000 tonnes/year)+	13,690	11.8	0.55	0.73

\+ based on a 350-day year

5.03 Impact of Metakaolin Use in Concrete

Concrete use in the Lower Mainland area of British Columbia currently represents about 4.3 million t/year. About 25% of this total comprises high strength applications, where SCM's can be used to enhance desirable properties. This would represent about 1.075 million t/year.

In order to evaluate the potential implications on CO_2 emissions with partial replacement of Portland cement (PC) by MK, a reference condition was established with the following composition for concrete:

Table 5.05
Reference Concrete Composition

Component	% (w/w)	
	Cement	Concrete
Metakaolin	0	0
Fly ash	25	3.8
Portland cement	75	11.3
Aggregate	-	79
Water	0.4	6
Total CM	-	15
Total Concrete		100

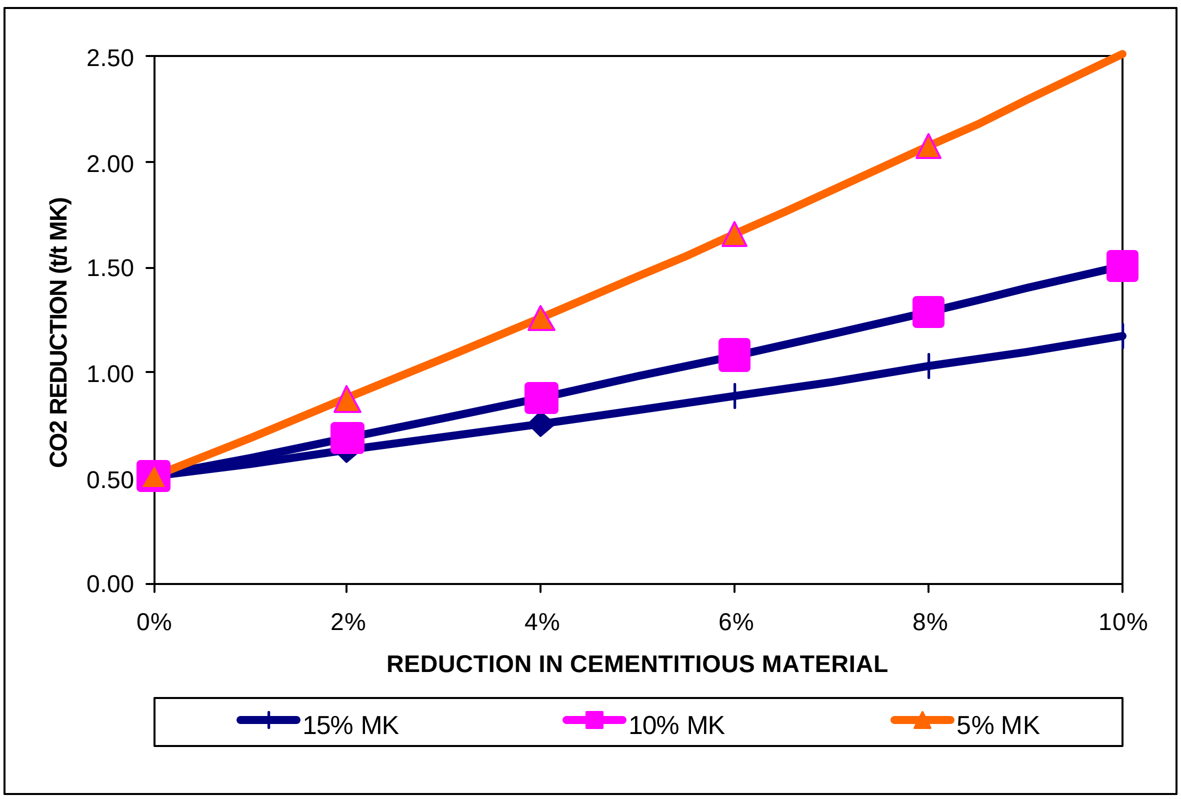
The MK content would be varied from 0 - 15% of cementitious material (CM) for total CM levels in concrete of 15% (reference condition) to 13.5% (a 10% reduction). Fly ash (FA) content would remain unchanged on a kg/m^3 concrete basis, while MK would be used to replace PC. This would result in the FA content increasing from 25% to 28% of the CM when the total CM was reduced by 10%.

The CO_2 generated through PC manufacture was estimated at 0.90 t/t PC [36]. Production of MK using the TTL process led to a CO_2 generation of 0.37 t/t MK (Table 5.01). Transportation of MK from Ft. McMurray to the Vancouver area would generate about 0.016 kg CO_2/KM/t MK [41] or 0.022 t CO_2/t MK. There should be little net change for GHG's generated through transport on the Lower Mainland, as a reduction in PC shipments would be largely offset by MK and increased levels of aggregate.

Figure 5.02 illustrates the change in unit CO_2 emissions as a function of MK content, for a reduction in CM from 0 - 10%. This graph shows that the most significant reduction in unit CO_2 emissions occurs at 5% MK, and declines with increasing MK substitution of PC. For example, if the total CM can be reduced by 10% by replacing 5% of the PC with MK, then the net CO_2 emissions will decease by 2.5 tonnes for every tonne of MK used. At this condition, 1 tonne MK would replace 3.2 tonnes PC and none of the FA. Further testing is required to determine the reductions in total CM possible at various MK levels that will still produce an acceptable quality concrete. The basis for the net CO_2 amount is 0.9 tonnes CO_2 reduced for each tonne of PC reduced, and 0.39 tonnes CO_2 produced for each tonne of MK FOB Vancouver, BC.

Figure 5.02

CO_2 Reduction Per Tonne MK Used



5.04 Potential Environmental Benefits That Would Accrue from MK Use

Potential benefits would include the following.

a. MK use in cement would contribute to a reduction in the CO_2 signature of concrete.

b. Within the limits of MK production capacity, recovery of kaolin from MFT's at the oil sands plants would have the potential to reduce the level of MFT's by about 43% based on the TTL process.

c. There would be no meaningful solid waste requiring separate disposal. Residual solids from the MK manufacturing process would be returned to the tailings ponds with effluent from the thickening process.

d. Dependent on the residual solids content, filtrate from the drum filter may be suitable for reuse within the oil sands processing plant, thereby reducing fresh water requirements. Based on the TTL process, volumes were estimated at about 16.6 m^3/hour.

e. Bitumen recovered in the TTL process (about 7,250 t/year) would be available to improve oil recovery efficiency from the tar sands. This is based on a MK production capacity of 37,000 t/year.

f. The MK demand curve (Figure 2.01) shows that as manufacturing costs decrease towards those for PC, the potential viability is enhanced for a large scale process facility in Ft. McMurray with a production approaching one million tonnes per annum. A plant of this size would contribute to a significant decrease in the GHG signature for concrete, and may warrant further consideration.

5.05 Environmental Impacts From the Manufacture and Use of Metakaolin

Potential disadvantages would include the following.

a. Drying and calcining of kaolin from MFT's would require natural gas. For a MK production capacity of 37,000 t/year, gas requirements would represent about 120,250 GJ/year (3.25 GJ/t MK). Residual bitumen in the feed to the calciner represents about 0.85 GJ/t MK and was applied as a credit in calculating the natural gas requirements. Total fuel energy requirements for MK production were estimated at 4.1 GJ/t MK.

b. Operation of the calciner and dryer would result in the emission of other contaminants to atmosphere (Table 5.01). These emissions are minimal when compared to those from the oil sands plants in Ft. McMurray and cement manufacture in the Lower Mainland. (Table 5.04).

c. Production of MK from MFT's at Ft. McMurray would result in an increase in CO_2 emissions of about 0.37 t/t MK. Generation of other GHG's would be minor.

d. Transportation of MK from Ft. McMurray to Vancouver would increase CO_2 emissions by about 0.022 t/t MK or some 815 t/year (for 37,000 t MK/year).

6.00 CONCLUSIONS AND RECOMMENDATIONS

Following are the key conclusions drawn from this study:

a. MK produced from the oils sands tailings is technically viable as an SCM for use in concrete.

b. Although several investigators have studied MK derived from mined kaolin, research on oil sands derived MK is limited.

c. Research indicates that MK derived from the oil sands tailings improves the performance of concrete in a similar way to SF, which is about 85-90% as much as pure MK

d. A precondition to considering the viability of extracted MK is that it can be supplied at a low enough cost to provide economic benefits to ready mix concrete suppliers with resulting demand that is adequate to justify an extraction plant.

e. SF use in concrete is limited to a small volume of high strength or high durability concrete applications. For this reason, demand for MK as a lower cost replacement for SF, is not relevant to the extraction plant economics.

f. A delivered selling price of $300/tonne for extracted MK may provide economic benefits to ready mix suppliers and generates a return on capital employed for a 37,000 tonne/year extraction plant. Increasing the size of the extraction plant to 74,000 tonnes/year, lowers the delivered cost of MK to $280/year and provides a similar return on capital employed.

g. Based on the assumptions presented in this analysis, there is an economic benefit to ready mix suppliers by using extracted MK priced in the range of $280-$300/tonne, in ternary blends with FA and PC, for concretes with adequate strength levels to enable a 10% reduction in total CM.

h. Demand in Western Canada for MK at these price levels in concrete is estimated to be in the range of 20-24,000 tonnes/year. Markets in the contiguous US states of Montana, Idaho and Washington which would require similar freight rates to those used in this study, must be included in the demand analysis to justify a 30-40,000 tonne/year extraction plant.

i. At a delivered selling price of $280 to $300/tonne, returns to the stakeholders (ready mix suppliers, CM suppliers, oil sands operators) are insufficient to warrant further work on this project. However, the potential demand for extracted MK priced in the range of PC are significant enough to justify further analysis of plant economics of scale.

j. MK use in cement would contribute to a reduction in the CO_2 signature of concrete.

On a very preliminary basis, this study indicates there may be economic benefits to ready mix suppliers by using MK in ternary blends only if it enabled a 10% reduction in total CM for the same strength levels. In order to provide credibility to these assumptions, we recommend that tests be done that assess the economic efficiency of ternary, iso-strength blends with various levels of cementitious materials and FA/MK/PC ratios. Confirmation of an adequate reduction in CM to enable savings to the ready mix suppliers may justify additional trial and plant feasibility work.

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APPENDIX 1
GLOSSARY OF TERMS

APPENDIX 1 - GLOSSARY OF TERMS

ACT	Advanced Cement Technologies
Al_2O_3	Aluminum oxide
$Al_2Si_2O_5(OH)_4$	Hydrated aluminium disilicate,
ASR	Alkali silica reaction
BTU	British Thermal Unit
CAH	Calcium-aluminate-hydrate
CaO	Calcium oxide
CASH	Calcium-aluminate-silicate -hydrate
CH	Calcium hydroxide
CH_4	Methane
CM	Cementitious material
CO	Carbon monoxide
CO_2	Carbon dioxide
CSH	Calcium-silicate-hydrate
FA	Fly ash
Fe_2O_3	Ferric oxide
FOB	Free on board
GGBFS	Ground granulated blast furnace slag
GHG	Greenhouse gas
GJ	Gigajoules
GVRD	Greater Vancouver Regional District
GWP	Global Warming Potential
h	Hour
HFC's	Hydrofluorocarbons
IRR	Internal rate of return
K_2O	Potassium oxide
kW/t	Kilowatt/tonne

lbs	Pounds
m^3	Cubic metre
MFT	Mature Fine Tailings
MgO	Magnesium oxide
MK	Metakaolin
N_2O	Nitrous oxide
Na_2O	Sodium oxide
NE	Northeast
NLK	NLK Consultants Inc.
NOx	Nitrogen oxides
P_2O_5	Phosphorous pentoxide
PC	Portland cement
PFC's	Perflurocarbons
PM	Particulate matter
PM10	Particulate matter with an aerodynamic diameter less than 10 microns
PM25	Particulate matter with an aerodynamic diameter less than 2.5 microns
ROI	Return on investment
scf	Standard cubic feet
SCM	Supplementary cementitious materials
SE	Southeast
SF	Silica fume
SF_6	Sulphur hexafluoride
SiO_2	Silicon dioxide
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
T	Tonne
TiO_2	Titanium dioxide
TTL	Tynebridge Technologies Ltd.
USEPA	United States Environmental Protection Agency
USG	United States gallon
w/w	Weight to weight

APPENDIX 2
FEASIBILITY GRADE ESTIMATE

15 AUGUST 2002

FEASIBILITY GRADE ESTIMATE OF COST

ITEM DESCRIPTION	LABOUR	MATERIAL	TOTAL
Direct Costs:			
Site Work	541,000	383,000	924,000
Structural	475,000	900,000	1,375,000
Heating and Ventilating	40,000	100,000	140,000
Equipment	1,795,000	8,722,000	10,517,000
Electrical	419,000	515,000	934,000
Instrumentation	200,000	550,000	750,000
Piping	950,000	750,000	1,700,000
Total Direct Cost	**4,420,000**	**11,920,000**	**16,340,000**

Mill Indirects:	
Spares	400,000
Engineering and Project Management	3,000,000
Temporary Construction and Field Services	300,000
Suppliers' Services	100,000
Total Mill Indirects:	**3,800,000**
Owner Indirects:	
Building Permits	500,000
Owner's Administration	150,000
Construction Management	800,000
Pre-project Costs	150,000
Pre-operating Costs (Training)	75,000
Start-up Costs (Contr. Attend. During Start-up)	25,000
Total Owner Indirects:	**1,700,000**
ESCALATION	Not Included
CONTINGENCY	**2,460,000**

Costs NOT included:
- Construction Insurance
- Escalation
- Goods & Services Tax
- Interest during Construction
- Production Losses
- Sitework Interruptions
- Working Capital

TOTAL ESTIMATED COST **CDN $ 24,300,000**

FEASIBILITY GRADE ESTIMATE OF COST

ITEM	D E S C R I P T I O N		LABOUR	MATERIAL	TOTAL
000	**SITE WORK :**				
001	Land Acquisition				Not Included
002	Earthwork		300,000	90,000	390,000
003	Roads and Parking		60,000	40,000	100,000
004	Rail Spur		160,000	215,000	375,000
005	Fencing		21,000	38,000	59,000
	Sub-total		**541,000**	**383,000**	**924,000**
100	**STRUCTURAL :**				
101	Building - Kaolin Recovery		475,000	900,000	1,375,000
	Sub-total		**475,000**	**900,000**	**1,375,000**
150	**HEATING AND VENTILATING :**				
155	Heating and Ventilating		40,000	100,000	140,000
	Sub-total		**40,000**	**100,000**	**140,000**
200	**PROCESS EQUIPMENT :**				
201	Pump - MFT Transfer	From Tailings Pond	5,000	9,000	14,000
202	Tank - Dispersant Storage				By Vendor
203	Pump - Dispersant Metering		2,000	3,000	5,000
204	Mill - Attrition	Four cell	79,000	735,000	814,000
205	Tank - Primary Clarifier	6.25m dia.	58,000	44,000	102,000
206	Mechanism - Primary Clarifier		32,000	62,000	94,000
207	Tank - Bitumen	4.5m dia.x 3m H, 50m3	52,000	34,000	86,000
208	Coil - Bitumen Tank Steam Heating		2,000	3,000	5,000
209	Pump - Bitumen Transfer		5,000	6,000	11,000
210	Pump - Primary Clarifier Underflow		7,000	10,000	17,000
211	Tank - Thickener	16m dia.	137,000	166,000	303,000
212	Mechanism - Thickener		83,000	105,000	188,000
213	Cover - Thickener	Aluminum	12,000	20,000	32,000
214	Pump - Thickener Underflow		7,000	10,000	17,000
215	Tank - Thickener Overflow	4.5m dia.x 3.7m H, 60m3	57,000	38,000	95,000
216	Coil - Thickener Overflow Tank Steam Heating		2,000	3,000	5,000
217	Pump - Kaolin Slurry		3,000	5,000	8,000
218	Filter	1.8m dia.x 2.4m lg., drum type	40,000	275,000	315,000
219	Pump - Filter Slurry		3,000	5,000	8,000
220	Pump - Vacuum		12,000	110,000	122,000
221	Receiver - Vacuum		10,000	15,000	25,000
222	Pump - Filtrate		3,000	5,000	8,000

FEASIBILITY GRADE ESTIMATE OF COST

ITEM	D E S C R I P T I O N	LABOUR	MATERIAL	TOTAL
223	Dryer 6.3m dia.x 4.9m str.side	150,000	2,000,000	2,150,000
224	Conveyor - Dry Kaolin	12,000	55,000	67,000
225	Calciner	670,000	4,400,000	5,070,000
226	Hammermill	20,000	40,000	60,000
227	Blowline to Silo	27,000	15,000	42,000
228	Silo - Product Storage	125,000	325,000	450,000
229	Process Air Systems	38,000	75,000	113,000
230	Insulation - Equipment	91,000	114,000	205,000
231	Insulation - Piping	23,000	10,000	33,000
232	Hoists - Monorail	8,000	20,000	28,000
233	Painting and Labelling	20,000	5,000	25,000
	Sub-total	**1,795,000**	**8,722,000**	**10,517,000**
300	**ELECTRICAL :**			
301	Motors, M.C.C.'s, and Wiring	230,000	210,000	440,000
302	V.S. Controllers	9,000	25,000	34,000
303	Lighting - Interior	35,000	20,000	55,000
304	Yard Lighting and Parking Lot Plug-ins	22,000	13,000	35,000
305	Instrument Cabling	68,000	27,000	95,000
306	Communications	4,000	10,000	14,000
307	Primary Power Supply		By Alberta Power Authority	
308	Metering		By Alberta Power Authority	
309	Outdoor Substation	36,000	200,000	236,000
310	Feeders to MCCs	15,000	10,000	25,000
	Sub-total	**419,000**	**515,000**	**934,000**
400	**INSTRUMENTATION :**			
401	Distributed Control System Incl. Configuration	50,000	100,000	150,000
402	Field Instruments and Control Valves	150,000	450,000	600,000
	Sub-total	**200,000**	**550,000**	**750,000**
500	**PIPING :**			
501	Piping - Battery Limit	750,000	650,000	1,400,000
502	Piping tie-ins	200,000	100,000	300,000
	Sub-total	**950,000**	**750,000**	**1,700,000**
	TOTAL ESTIMATED DIRECT COST	**4,420,000**	**11,920,000**	**16,340,000**

APPENDIX 3
OPERATING COSTS AND CASH FLOW ANALYSIS

CASH FLOW ANALYSIS
37,000 T/Y METAKAOLIN

Year	Description	Costs	Revenue	EBITDA	Cumulative
2003	Capital	$12,000,000		-$12,000,000	-$12,000,000
2004	Capital	$12,300,000		-$12,300,000	-$24,300,000
2005	65% op.	$3,831,535	$3,940,500	$108,965	-$24,191,035
2006	90% op.	$3,986,010	$5,516,700	$1,530,690	-$22,660,345
2007	100% op.	$4,139,190	$7,092,900	$2,953,710	-$19,706,635
2008	100% op.	$4,217,630	$7,881,000	$3,663,370	-$16,043,265
2009	100% op.	$4,217,630	$7,881,000	$3,663,370	-$12,379,895
2010	100% op.	$4,217,630	$7,881,000	$3,663,370	-$8,716,525
2011	100% op.	$4,217,630	$7,881,000	$3,663,370	-$5,053,155
2012	100% op.	$4,217,630	$7,881,000	$3,663,370	-$1,389,785
2013	100% op.	$4,217,630	$7,881,000	$3,663,370	$2,273,585
2014	100% op.	$4,217,630	$7,881,000	$3,663,370	$5,936,955
2015	100% op.	$4,217,630	$7,881,000	$3,663,370	$9,600,325
2016	100% op.	$4,217,630	$7,881,000	$3,663,370	$13,263,695
2017	100% op.	$4,217,630	$7,881,000	$3,663,370	$16,927,065
2018	100% op.	$4,217,630	$7,881,000	$3,663,370	$20,590,435
2019	100% op.	$4,217,630	$7,881,000	$3,663,370	$24,253,805
2020	100% op.	$4,217,630	$7,881,000	$3,663,370	$27,917,175
2021	100% op.	$4,217,630	$7,881,000	$3,663,370	$31,580,545
2022	100% op.	$4,217,630	$7,881,000	$3,663,370	$35,243,915
2023	100% op.	$4,217,630	$7,881,000	$3,663,370	$38,907,285
2024	100% op.	$4,217,630	$7,881,000	$3,663,370	$42,570,655
			IRR	**10.1%**	

Capital Cost	$24,300,000	
	$/t	Rate
Oper. Cost	207.11	50%
	153.90	70%
	124.30	90%
	113.99	100%
Sell ($)	**303**	
Frt ($)	**90**	
Prod (t)	**37,000**	at 100%

CASH FLOW ANALYSIS
74,000 T/Y METAKAOLIN

	Year	Description	Costs	Revenue	EBITDA	Cumulative
-1	2003	Capital	$20,000,000		-$20,000,000	-$20,000,000
0	2004	Capital	$23,740,000		-$23,740,000	-$43,740,000
1	2005	40% op.	$4,410,104	$4,795,200	$385,096	-$43,354,904
2	2006	60% op.	$4,721,496	$7,192,800	$2,471,304	-$40,883,600
3	2007	80% op.	$5,027,856	$9,590,400	$4,562,544	-$36,321,056
4	2008	100% op.	$5,336,880	$11,988,000	$6,651,120	-$29,669,936
5	2009	100% op.	$5,336,880	$11,988,000	$6,651,120	-$23,018,816
6	2010	100% op.	$5,336,880	$11,988,000	$6,651,120	-$16,367,696
7	2011	100% op.	$5,336,880	$11,988,000	$6,651,120	-$9,716,576
8	2012	100% op.	$5,336,880	$11,988,000	$6,651,120	-$3,065,456
9	2013	100% op.	$5,336,880	$11,988,000	$6,651,120	$3,585,664
10	2014	100% op.	$5,336,880	$11,988,000	$6,651,120	$10,236,784
11	2015	100% op.	$5,336,880	$11,988,000	$6,651,120	$16,887,904
12	2016	100% op.	$5,336,880	$11,988,000	$6,651,120	$23,539,024
13	2017	100% op.	$5,336,880	$11,988,000	$6,651,120	$30,190,144
14	2018	100% op.	$5,336,880	$11,988,000	$6,651,120	$36,841,264
15	2019	100% op.	$5,336,880	$11,988,000	$6,651,120	$43,492,384
16	2020	100% op.	$5,336,880	$11,988,000	$6,651,120	$50,143,504
17	2021	100% op.	$5,336,880	$11,988,000	$6,651,120	$56,794,624
18	2022	100% op.	$5,336,880	$11,988,000	$6,651,120	$63,445,744
19	2023	100% op.	$5,336,880	$11,988,000	$6,651,120	$70,096,864
20	2024	100% op.	$5,336,880	$11,988,000	$6,651,120	$76,747,984
				IRR	**10.0%**	

Capital Cost	$43,740,000	
	$/t	Rate
Oper. Cost	148.99	40%
	106.34	60%
	84.93	80%
	72.12	100%
Sell ($)	**282**	
Frt ($)	**120**	
Prod (t)	**74,000**	at 100%

OPERATING COSTS

37,000 Tonnes

	Units	Quantity	Cost/unit	Cost/year	$/t
Capital		$24,300,000			
Equipment	$	$10,517,000			
Production	t/yr	37,000			
Hours	hr/yr	8,400			
Operating cost					
Labour	$/yr	22	$130,320	$2,867,040	$77.49
Reagents	kg/t MK	12.863	0.217	$103,372	$2.79
Gas	GJ/t MK	3.26	3.40	$410,108	$11.08
Power	kW/t MK	158.86	0.044	$258,624	$6.99
Maintenance	% equip	5.5%	$10,517,000	$578,435	$15.63
TOTAL				$4,217,579	**$113.99**

74,000 Tonnes

	Units	Quantity	Cost/unit	Cost/year	$/t
Capital		$43,740,000			
Equipment	$	$16,827,200			
Production	t/yr	74,000			
Hours	hr/yr	8,400			
Operating cost					
Labour	people	22	$130,320	$2,867,040	$38.74
Reagents	kg/t MK	12.863	0.217	$206,744	$2.79
Gas	GJ/t MK	3.26	3.40	$820,216	$11.08
Power	kW/t MK	158.86	0.044	$517,248	$6.99
Maintenance	% equip	5.5%	$16,827,200	$925,496	$12.51
TOTAL				$5,336,745	**$72.12**

APPENDIX 4
MARKET SURVEY QUESTIONNAIRE

APPENDIX 4 - MARKET SURVEY QUESTIONNAIRE

FINAL QUESTIONNAIRE

Following is a suggested approach for the questionnaires.

1.00 BACKGROUND

There are four SCM's that are of interest to us:

- Fly ash
- Ground slag
- Silica fume (SF)
- Metakaolin (MK)

The first two are lower cost than Portland cement (PC) and are used primarily for cost reduction. Silica fume and MK are considerably more expensive than PC and are used to impart specific properties. PC costs about $0.12/kg, MK about $0.65/kg and SF about $1.00/kg.

High early strength and sulphate resisting PC which may justify more expensive SCMs account for about 4% each of total PC consumption (123 million tonnes in US & Canada). About 80,000 tonnes of MK is currently used in PC. Therefore to attain a reasonable demand volume for MK, it probably has to approach a price level where it can be justified as a cost saving component in the general use category which accounts for 88% of PC consumption. Although, as a conclusion, this will be confirmed by the research, it does establish a direction in which to phrase the questions and probe the respondents.

2.00 RESPONDENTS

There are five categories of respondents, each with different interview objectives that we need to develop questionnaires for:

a. **Specifiers and Researchers**; This includes groups such as Levelton and CANMET. The objective is to assess the performance tradeoffs of MK compared to mixtures with SF and100% PC for various applications.

b. **Additive Suppliers**; This includes companies such as Master Builders, Pozzolanic etc. The key interview objective is to establish which SCMs they are supplying and to what markets and their relative price levels. Their views on the price elasticity of demand of the respective SCMs will also be sought.

c. **Concrete Suppliers**; This includes the large integrated producers such as Lafarge and Tilbury as well some of the smaller ready-mix suppliers. The objective will be to assess their decision making process re: concrete batch alternatives for specific end-uses and the cost-quality tradeoffs they use in making these decisions. Their opinions on the demand for MK at various pricing levels will be sought.

d. **End-Users**; The focus will be on end-use groups that specify batch mix contents as well as the final specifications of the concrete. This includes groups such as the GVRD, municipalities and the department of highways.

e. **Industry Associations**; The main objective will be to determine the size of the concrete end-use segments where MK can offer potential economic and performance benefits at lower price levels and the resultant potential demand for MK.

3.00 INTERVIEWS

Each interview or request for interview will start with a basic introduction:

a. NLK has been retained by the EcoSmartTM Concrete Project to undertake a study to establish the economic viability of using calcined clay reclaimed from the oil sands tailing ponds near Fort McMurray as a supplementary cementing material (SCM) in concrete.

b. Explain the EcoSmartTM Concrete Project and participants as necessary.

c. The specific comments from the interview will be kept confidential. However, in return for your cooperation, we will provide you a synopsis of the market research and the final report will be available to the public.

3.01 Specifiers and Researchers

a. How does MK compare with SF re: the properties it imparts to concrete in terms of:

   1. Early age and later age strength.

   2. Durability/permeability.

   3. Slump and requirement for plasticizers.

   4. Reduction in the total amount of cement required in the concrete mix.

   5. Optimum percentages of SF vs. MK.

b. How do concrete mixes with MK compare with cement only concrete for high strength mixes.

   1. The concrete strength levels at which MK can be justified and required percentage of MK to obtain these levels.

   2. Plasticizer requirements at these strength levels, for cement only and MK mixes, to maintain the proper slump.

   3. Reduction in total cement requirements, at these strength levels, with these percentages of MK.

c. Use of MK with lower cost SCMs such as fly ash and ground slag:

   1. Can MK be used in conjunction with fly ash or ground slag to offset the longer setting time caused by higher percentages of fly ash in the concrete mix.

   2. Can the use of MK in conjunction with fly ash increase the total SCM percentage in the mix, and maintain the same properties.

   3. What are some examples of MK/fly ash mixes in terms of total SCM content and related concrete properties.

   4. Are there any issues regarding the properties of MK recovered from the tar sands, compared to the material currently on the market that we should review with the respondents.

3.02 Additive Suppliers

a. After the introduction, question their familiarity with MK as a SCM and their experience with it. If they have limited experience with MK review summary of MK and SF comparisons.

b. What cement/concrete additives do they supply with particular focus on SCMs.

c. What markets or end-uses do they supply the SCM's to i.e., high early strength, high strength for specific end uses such as tall buildings (above what MPa)., low permeability for such things as bridge decks etc.

d. What are the relative volumes and price levels ('ball-park') of the respective SCMs.

e. Question the respondents on how price sensitive the additive buyers are. Focus should be on MK if they are familiar with it. If they are unfamiliar with it, assume it has similar properties to silica fume, but without making the concrete sticky.

    1. How much additional volume can be sold if it were 50% of the current price.

    2. At 25% of the current price.

    3. To what respective end-uses could the lower cost MK be marketed to.

3.03 Concrete Suppliers

a. Are you currently providing SCMs in your concrete mixes.

    1. If yes, which SCMs are you supplying. Have they done test work on MK as SCM that they could review with us.

    2. If they are not offering MK or are not familiar with it, provide the comparison with SF.

b. What are the major markets (end-uses) the SCM containing concrete mixes are being provided to,

    1. What are their relative volumes.

c. Does your company specify the batch mix to meet a certain specification or does the end-user.

    1. Are there standard batches or can custom batches be prepared to meet a specification at the lowest cost.

    2. Are there testing facilities either locally or at a central region to prepare and assess the non-standard batches.

d. At what price level would MK have to decline to (relative to SF and PC) to provide economic benefits in their respective batch mixes

1. What potential increases in MK volume are there at this price level.

2. Probe for the total cost of their concrete mixes including other additives such as plasticizers.

3. Probe for tradeoffs in total cement content reductions with MK and use of MK in conjunction with fly ash that may allow them to average down the costs of their cement mix by increasing the total SCM content.

4. Given their familiarity with MK in test work done, what are the barriers to specifying MK in their batches.

3.04 End-Users

a. What are the broad categories of end-uses for concrete in which your group specifies concrete mixtures.

b. Are SCMs specified in the mixes and for what final concrete specifications.

1. Have they considered or are they familiar with MK as a SCM. If not, review its properties and comparison with SF.

c. Are there end-uses where they have specifications for both permeability (durability) and strength but where durability is the major concern (i.e., curbs and sidewalks)

1. If so, could they specify a lower strength concrete that had the same permeability by using MK, but at a lower cost.

2. Or, could they specify higher durability/strength concrete but reduce its total volume, thus lowering costs.

3.05 Industry Associations

a. What regions in North America and for what end-uses is MK currently used as a SCM.

1. Is it being used in regions where it is available and more economically priced.

b. What are estimates of the volumes of concrete used in North America in end-uses where MK can have economic benefits based on the market research undertaken.

1. Has the association done any market research on MK.

APPENDIX 5

CEMENTITIOUS MATERIAL CONSUMPTION

Portland Cement

2001 PC consumption ('000 tonnes)	USA	110,000
	Canada	13,000
	North America	123,000
Avg PC mill net (2000) US$/tonne		$77
2001 estimate for concrete ('000 tonnes)		1,118,182
PC breakdown by end user	ready mix batch plants	74%
	concrete prod manuf	13%
	contractors	7%
	bldg matl dealers	4%
	other	2%
PC breakdown by type	general use	88%
	high early strength	4%
	sulfate resisting	4%
	blended	1%
	misc	3%

source: USGS

Kaolin Clay

USA data

2000 total kaolin data ('000 tonnes):				
Production	8,800			
Exports	2,740			
Consumption	6,060			
Kaolin processing breakdown:	%	$/tonne		
Water washed	55%	$100		
Airfloat	16%	$46		
Calcined (pigment grade & refractory grade)	14%	$219	$28 for refractory	$294 for pigment
Delaminated	13%	$103		
Unprocessed	2%	$13		
Average		$106		
Usage breakdown (of production):	'000 tonnes	%		
Paper filler/coating	5,355	60.9%		
Paint	740	8.4%		
Ceramics	685	7.8%		
Refractories	425	4.8%		
Fiberglass	305	3.5%		
Rubber	260	3.0%		
Brick	125	1.4%		
Portland cement	80	0.9%	clinker & SCM?	
Other	825	9.4%		
	8,800			

source: USGS

Fly Ash

USA data only

Total 2000 production ('000 tonnes)	57,140	
Total 2000 usage	18,225	
% utilization	31.9%	
Usage breakdown:		
Cement/concrete/grout	9,610	53%
Raw feed for cement clinker	1,029	6%
Fills	3,003	16%
Road base	1,097	6%
Mining	1,046	6%
Waste stabilization	1,803	10%
Misc	637	3%

source: ACAA

Granulated Slag

USA data

The iron & steel industry does not measure slag production, therefore only consumption data exists.

2000 Iron slag production estimate ('000 tonnes)	12,000	
2000 Steel slag production estimate ('000 tonnes)	13,000	
Total	25,000	

2000 slag usage in USA:	'000 tonnes	$/tonne
air cooled iron blast furnace slag	8,900	$6.6
expanded & granulated iron blast furnace slag	2,300	$27.2
steel slag	5,100	$3.9
Total	16,300	$8.6

Iron slag usage (2001 data):	
road bases	37%
asphalt aggregates	19%
cement/concrete (incl usage as aggregate, clinker & SCM)	16%
fill	9%
other	19%

source: USGS

APPENDIX 6
CONCRETE COSTS

CONCRETE COSTS
(MK @ $303/TONNE)

Metakaolin Replacement

		Wt%	Kg/m3	Unit $/kg	$/m3	$/t concrete
MK	0%	0.0%	0	0.303	0	0.00
FA	0%	0.0%	0	0.075	0	0.00
PC	100%	15.0%	360	0.130	46.80	19.50
Aggregate		79.0%	1896	0.015	28.44	11.85
Water	0.40	6.0%	144	0	0	0.00
Total CM		15.0%	360		46.80	19.50
Total Concrete		100.0%	2400		**75.24**	**31.35**

		Wt%	Kg/m3	Unit $/kg	$/m3	$/t concrete
MK	0%	0.0%	0	0.303	0	0.00
FA	25%	3.8%	90	0.075	6.75	2.81
PC	75%	11.3%	270	0.130	35.1	14.63
Aggregate		79.0%	1896	0.015	28.44	11.85
Water	0.40	6.0%	144	0	0	0.00
Total CM		15.0%	360		41.85	17.44
Total Concrete		100.0%	2400		**70.29**	**29.29**

CM Reduction	10%	Wt%	Kg/m3	Unit $/kg	$/m3	$/t concrete
MK	5%	0.7%	16	0.303	4.9086	2.05
FA	25%	3.4%	81	0.075	6.075	2.53
PC	70%	9.5%	227	0.130	29.484	12.29
Aggregate		81.1%	1946	0.015	29.20	12.17
Water	0.40	5.4%	130	0	0	0.00
Total CM		13.5%	324		40.47	16.86
Total Concrete		100%	2400		**69.66**	**29.03**

CONCRETE COSTS
(MK @ $282/TONNE)

Metakaolin Replacement

		Wt%	Kg/m3	Unit $/kg	$/m3	$/t concrete
MK	0%	0.0%	0	0.282	0	0.00
FA	0%	0.0%	0	0.075	0	0.00
PC	100%	15.0%	360	0.130	46.80	19.50
Aggregate		79.0%	1896	0.015	28.44	11.85
Water	0.40	6.0%	144	0	0	0.00
Total CM		15.0%	360		46.80	19.50
Total Concrete		100.0%	2400		**75.24**	**31.35**

		Wt%	Kg/m3	Unit $/kg	$/m3	$/t concrete
MK	0%	0.0%	0	0.282	0	0.00
FA	25%	3.8%	90	0.075	6.75	2.81
PC	75%	11.3%	270	0.130	35.1	14.63
Aggregate		79.0%	1896	0.015	28.44	11.85
Water	0.40	6.0%	144	0	0	0.00
Total CM		15.0%	360		41.85	17.44
Total Concrete		100.0%	2400		**70.29**	**29.29**

CM Reduction	10%	Wt%	Kg/m3	Unit $/kg	$/m3	$/t concrete
MK	5%	0.7%	16	0.282	4.5684	1.90
FA	25%	3.4%	81	0.075	6.075	2.53
PC	70%	9.5%	227	0.130	29.484	12.29
Aggregate		81.1%	1946	0.015	29.20	12.17
Water	0.40	5.4%	130	0	0	0.00
Total CM		13.5%	324		40.13	16.72
Total Concrete		100%	2400		**69.32**	**28.88**