EcoSmart™ Concrete Project

A Concrete Contribution to the Environment™

METAKAOLIN STUDY

Pre-Feasibility Review of the Potential for Developing Metakaolin from Oil Sands Operations for Use in Concrete

Prepared for:
Action Plan 2000 on Climate Change – Minerals and Metals

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1. Executive Summary

The following report evaluates the potential of metakaolin recuperated from oil sands tailing ponds in North Alberta, as a supplementary cementing material (SCM) for concrete.

Oil sands operations produce vast quantities of tailings containing extremely fine clays that prevent the reuse of process water from the tailings ponds. Preliminary research has indicated that this fine material can be processed into a product similar to metakaolin (MK). Metakaolin is a valuable product with many commercial uses, including as a high performance SCM. Extracting the fine clay from the ponds to produce SCM would have two benefits: clarifying the process water for reuse in the operations while producing a valuable product from a by-product.

The study finds however that, while it is technically feasible, the concept is uneconomical for many reasons. The material that can be produced from the pond – called calcined mature fine tailings or CMFT – while similar to MK, has lower quality and performance than the products currently on the market. Another shortcoming is that CMFT is grey while metakaolin from virgin kaolin is white. Therefore, in performance and appearance, CMFT cannot compare to MK. Rather, it is more like fly ash (FA), another SCM abundantly available in Alberta, but at a much lower price than MK. Furthermore, the oil sand region is isolated, landlocked and far from the market for concrete. Because of the cost of extracting, drying, calcining, and transporting the material, CMFT cannot compete against FA, and the study concludes on the non-feasibility of the concept.

The oil sand industry still wants to resolve its water and pond issues, and continues to investigate ways to process the fine tailing. If this research is successful and CMFT with improved quality, color and cost can be produced, then it will be worthwhile to re-examine the case and see if the product can be used in concrete.

2. Introduction

The use of Portland cement (PC) in concrete has significant greenhouse gas (GHG) implications, where the manufacture of each tonne of PC generates approximately 0.9 tonnes of CO_2 emissions[1]. The "GHG signature" of concrete can be reduced by partial replacement of PC with supplementary cementing materials (SCM). Typical SCMs include fly ash, ground granulated blast furnace slag, and silica fume, ground limestone, natural pozzolans and metakaolin.

It has been discovered that the by-product of oil sands operations, namely the clay from tailings ponds, can be processed into a material with similar properties to metakaolin for use in paper making, ceramics, concrete, and other industrial applications. The oil sands operations in northern Alberta produce vast quantities of tailings, which are stored in gigantic tailings ponds. Fine clay, which represents a significant part of these tailings, takes a long time to settle, and therefore makes it very difficult to recycle the process water. Extraction and processing of this clay is a promising means of turning the by-product into a value-added product and clarifying the process water for reuse in the operations.

Starting from existing scientific and technical information produced by the oil sands industry and the research community, this study investigates the validity and feasibility of the concept of reclaiming and processing the tailings into a product that can be used as an SCM in concrete. In the study, the EcoSmart™ Concrete Project has reviewed the

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[1] Malhotra, 1999.

existing research and technical studies, has commissioned an independent pre-feasibility study, and engaged the various stakeholders in the process and decision-making.

2.1. Study Objectives

The objectives of this study are:

1. to assess the potential for developing metakaolin from oil sands operations for use as an SCM in concrete (on technical, economic, and environmental basis); and
2. to determine whether further exploration of this technology is justified.

2.2. Scope of Report

This study was conducted as the first phase of a two-phase feasibility study for developing this SCM technology, as indicated on Figure 1. This report reviews the existing information and updates the technical, economic, and environmental assumptions for calcination of the oil sands clay. The extraction process proposed in a previous study by Syncrude[2], one of the oil sands operators, was assumed technically viable and was not re-examined. This report also includes the input of the cement and concrete industry as well as the oil sands industry in terms of the current market for this material and willingness to develop the product, and thus, the market. Finally, the role of the Federal Government was also taken into account in developing this technology. The outcome of the study is a compilation and summary of the existing and EcoSmart-commissioned information, and a clear overview of the potential and the challenges of the concept.

[2] Tynebridge, 1998.

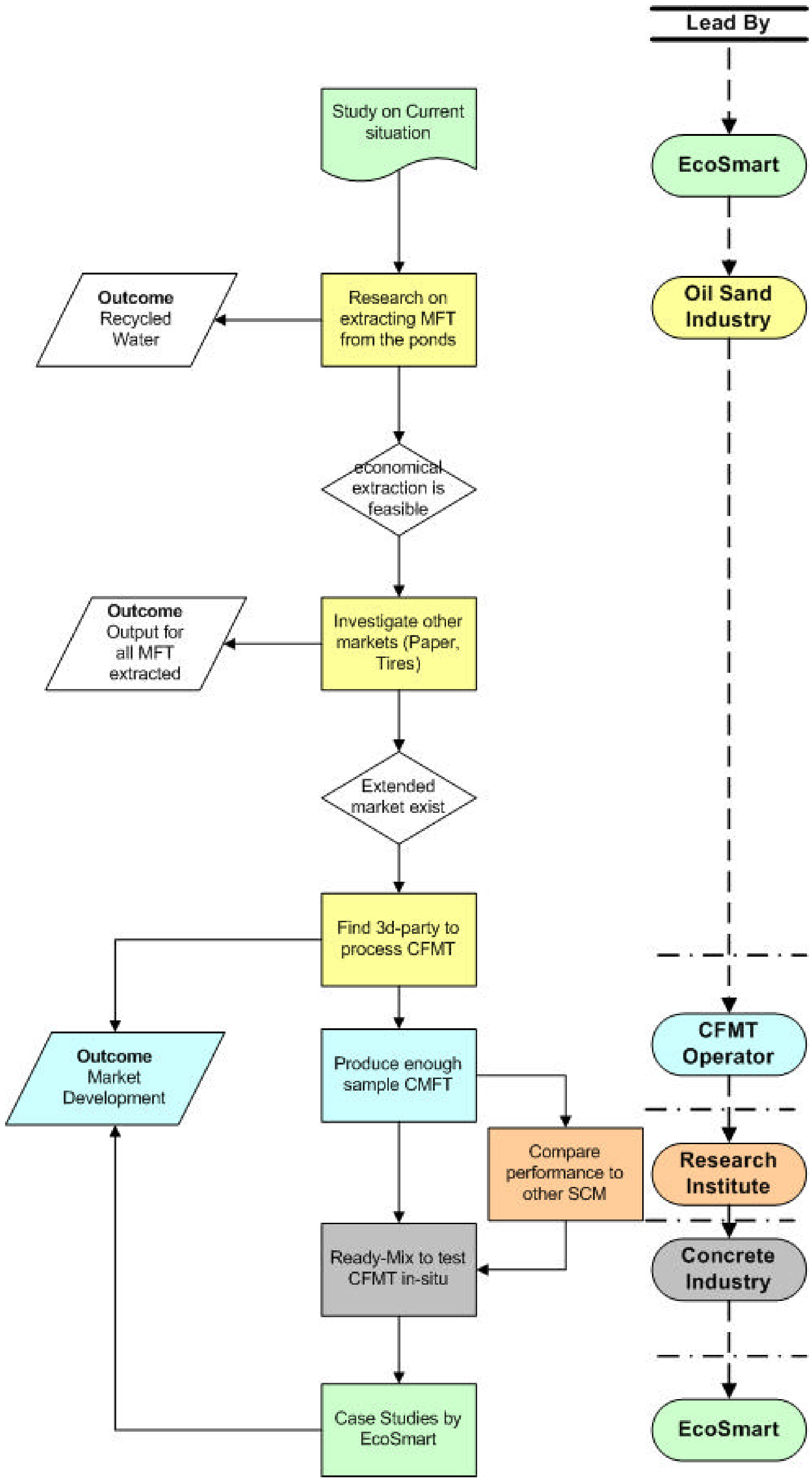

Figure 1: Scope of the EcoSmart™ Metakaolin Study

2.3. About EcoSmart

The objective of the EcoSmart™ Concrete Project (EcoSmart) is to minimize the GHG signature of concrete by maximizing the replacement of Portland cement in the concrete mixtures with SCMs while maintaining or improving cost, performance, and constructability. EcoSmart is an industry-government partnership generating and transferring knowledge on reducing the CO_2 emissions from the construction industry.

3. Background

Numerous research and technical studies have pointed to the great potential of metakaolin (MK) as a supplementary cementing material with performance similar although slightly inferior to silica fume (SF) (see Table 3 in Section 7.1).

MK is produced by thermally processing pure kaolinite. Main sources of kaolinite as well as the key MK producers are located in clay deposits in Georgia, U.S. and Cornwall, U.K. The price of MK in Canada is about the same as SF and ranges between $400 and $600 per tonne depending on the location[3]. Besides concrete, other markets for kaolin and MK include the paper, ceramics, and fibre-cement boards industries.

Oil sands operations produce vast quantities of fine tailings collected in gigantic tailings ponds. Fine tailings comprise mainly of kaolinite, illite, and quarts. The details of the composition of fine tailings are provided in Section 3.1. Currently, the oil sand fields have a total of 400 million cubic meters of tailings, which contain up to 60 million tonnes of kaolin[4]. According to one of the oil sands companies in Alberta, their operations could produce up to 6 million tonnes of Calcined Mature Fine Tailing (CMFT) annually[5], a material similar but not equal in performance to MK.

Based on rough calculations by Syncrude alone, this oil sands operator could produce 3.3 million tonnes of kaolin during their 2003 production of 85 barrels of oil, as indicated in Table 1.

Table 1: Sample Calculation for Syncrude Kaolin Production Capability[6]

Product	Conversion Factors	Potential for Kaolin Production
1m^3 of MFT	1m^3 (1280kg) of MFT containing 30% solids (clay) produces 384kg of clay containing 40% kaolin	153.6 kg of kaolin per m3 MFT
1 barrel (bbl) of oil	It requires 1 m^3 of oil sand to produce 1 barrel of oil. Removal of that oil produces 1.1 m^3 of sand containing 0.25m^3 of MFT [(1280kg MFT x 0.25) x 0.3 solids x 0.4 kaolin]	38.4 kg of kaolin per bbl oil
2003 Production		
85 M bbl oil per year	**85 M x 38.4 kg of kaolin per year**	**3.3 M tonnes of kaolin per year**

[3] Personal Communication, Brad Pope, Pozzolanic, July 18, 2003.
[4] Wong et.al., 2002, p.1.
[5] NLK, 2002, p. 4-3.
[6] Personal Communication, Ted Lord, Syncrude Research, August 29, 2003.

3.1. Definitions

Portland cement (PC) is a hydraulic cement produced by pulverizing Portland cement clinker, usually in combination with calcium sulphate (gypsum). Portland cement clinker is a partially fused ceramic material consisting primarily of hydraulic calcium silicates and calcium aluminates.[7]

Supplementary cementing material (SCM) is a pozzolanic material that contains high proportions of silica and in some SCMs, alumina. When used in concrete as partial replacement of PC, it reacts with unreacted calcium hydroxide from the hydration of PC to form calcium silicate hydrates – the desired end product of PC hydration. SCMs include fly ash (FA), ground granulated blast furnace slag (GGBFS), silica fume (SF), natural pozzolans (NP), and metakaolin (MK).

Metakaolin (MK) is produced by calcining virgin kaolin.

Kaolin is a clay mineral consisting of the mineral kaolinite with admixtures of quartz and feldspar[8].

Tailings are the by-product of the oil sands operations, namely a mixture of water and the solid matter remaining after nearly all the oil is removed. Tailings include sand, clay, silt, residual bitumen and water.

Fine tailings (FT) are the small particles in suspension (10% solids) in the tailings pond, comprised mainly of clay and silt[9] suspended in water.

Mature fine tailings (MFT) are a gel-like substance (30% solids) composed of very slowly settling fine clay particles, and is made up mostly of water[10]. MFT contains the clay and silt particles remaining in suspension after 2-3 years of settlement[11]. The typical mineral composition of MFT includes approximately 23% kaolin, 17% illite (mica), 30% quartz, and small quantities of other minerals, including iron and titanium, as well as some organics. The iron and titanium in the MFT contribute to the unwanted dark colour in the material. The minerals in MFT comprise mainly of silica and alumina (at a ratio of approximately 2:1 to 3:1)[12]. Kaolinitic component in MFT can be concentrated up to 65% by weight.[13] MFT is near or at its terminal density and will not densify further under its own self-weight in the tailings pond.

Calcined mature fine tailings (CMFT) are produced by first separating out the finer fraction (primarily kaolin) from MFT and then heating this fraction to drive off the hydroxyl groups ($^{-}$OH) from the component oxides, i.e., thermal decomposition[14].

Unlike other SCMs, MK and CMFT are unregulated products. In addition, although MK and CMFT have similar properties, CMFT is inferior to MK because of impurities such as silica, illite, iron, and titanium. Research indicates that the effectiveness of MK from MFT as an SCM is approximately 85-90% that of pure MK[15].

[7] ACI Manual of Concrete Practice, 2003, ACI 116R-12-14.
[8] http://www.a-m.de/englisch/lexikon/kaolinit.htm, viewed on September 4, 2003.
[9] Personal Communication, Ted Lord, Syncrude Research, August 29, 2003.
[10] http://www.syncrude.com/research/04_03.html, viewed July 18, 2003.
[11] Personal Communication, Ted Lord, Syncrude Research, August 29, 2003.
[12] Omotoso, D. et.al., 2001 Presentation and Tynebridge, 1998, p. 1.
[13] Omotoso, D. et.al., 2001 Presentation.
[14] INSA, 2002 and Omotoso, D. et.al., 2001 Presentation.
[15] University of Calgary and Syncrude, October 2001.

3.2. Use of Metakaolin in Canada

Currently in Canada, metakaolin is only used in small quantities in British Columbia. It is imported from the U.S. and is used primarily in architectural and specialty concretes. The price of metakaolin in B.C. is approximately five times the price of Type 10 Portland cement.[16]

3.3. Use of Metakaolin in the World

The NLK study indicates that MK use in the concrete industry is very limited. In North America, it is commercially available as MetaMax®, and is produced in Georgia, USA by Engelhard Corporation. There is also a smaller source of MK in south-eastern USA. In the USA, the Departments of Transportation of New York, Illinois, Florida, and California approve the use of MK in concrete. There has also been some use of MK in concrete in New Zealand and in the Amazon Basin.[17]

3.4. Investigations of Metakaolin Production from Oil Sands Operations

In 1998, Syncrude Canada commissioned a study on clay recovery from MFT generated in its oil sands operations. The study was carried out by Tynebridge Technologies Limited. The study described a possible extraction process, the costs of production in a pilot plant, and scale up factors based on a pilot plant configuration that would use the smallest equipment available. The study defined the technology required to produce CMFT, and provided a simplified cash flow analysis indicating that the economics were reasonable, based on a selling price of $600/tonne[18]. However, the oil sands operators, including Syncrude, were not interested in pursuing this business venture themselves, but were receptive to making this opportunity available to an interested independent third party.

During 2001 and early 2002, following preliminary investigations and discussions with the oil sands industry, EcoSmart undertook as part of its mandate to follow up and further investigate the technical, economic and environmental potential and challenges of developing this source of metakaolin. Through this process, EcoSmart was to serve as a means to identify the interested third party. Stakeholder meetings were held in Alberta with representatives of three oil sands companies, the cement and concrete industry, the Federal Government and the research community. The meeting minutes may be found in the Appendices. As a result, it was decided to review, as part of a pre-feasibility study, the Tynebridge study in order to refine the numbers with more accurate information.

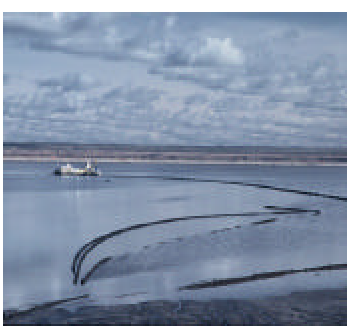

Figure 2: Fort McMurray, Alberta Oil Sands

In 2002, following further consultations to determine the scope, EcoSmart commissioned a pre-feasibility study. NLK Consultants Inc. was retained to complete this work. The study involved a market analysis, desktop research and industry interviews. The technical aspects of production and use of CMFT as an SCM were investigated, updating the economic analysis of the Tynebridge study, and incorporating environmental considerations. The NLK study halved the price of the MK product from the selling price identified in the Tynebridge study by refining the process costs, assuming that the extraction technology proposed was feasible, and assuming that a partial replacement of Portland cement by MK could reduce the total cementitious amount in a unit of concrete.

Following the completion of the report and into 2003, EcoSmart continued consultations with industry and the research community, concluding with a second stakeholder meeting in Alberta to identify the next steps in the technology exploration process. The minutes

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[16] Bouzoubaâ and Fournier, 2003, p. 5-6, 22-23.
[17] NLK, 2002, p. 4-8.
[18] Tynebridge, 1998, p. 8.

from this meeting are included in the Appendices. This report presents the outcome of the entire EcoSmart undertaking regarding this alternative SCM material.

The following sections of the report provide more details of the findings from the EcoSmart initiative.

3.5. Research into the Use of Metakaolin as an SCM

The NLK report summarizes the findings on the use of metakaolin as an SCM available from research literature. Overall, based on this literature review, the SCM potential of this material is promising. As a follow-up to the NLK report, EcoSmart engaged the world-renowned expertise of the Institut National des Sciences Appliqués de Lyon (INSA) and the materials expertise of AMEC Earth & Environmental, Burnaby, B.C., to provide additional insights into the technical potential of CMFT as an SCM. ICON/CANMET in Ottawa, ON, has been engaged in assessing the requirements of a concrete testing program for CMFT and has conducted a study into the current situation of SCMs in Canada.

4. Technical Evaluation

4.1. Extraction and Calcination Process

The extraction process described in the Tynebridge study and illustrated in Figure 3 involves the addition of sodium silicate as a dispersant (attrition mill) and removal of residual bitumen (primary clarifier) before further thickening (secondary thickener). The silt from the thickener is returned to the tailings ponds, while the kaolin-rich overflow is dewatered and spray dried. The clay (containing kaolinite, illite, iron, titanium, and traces of bitumen) is then calcined (hydroxyl groups removed at temperatures in the order of 600-800^{o}C).[19, 20]

[19] Tynebridge, 1998, p. 5.
[20] Wong et.al., 2002, p. 6.

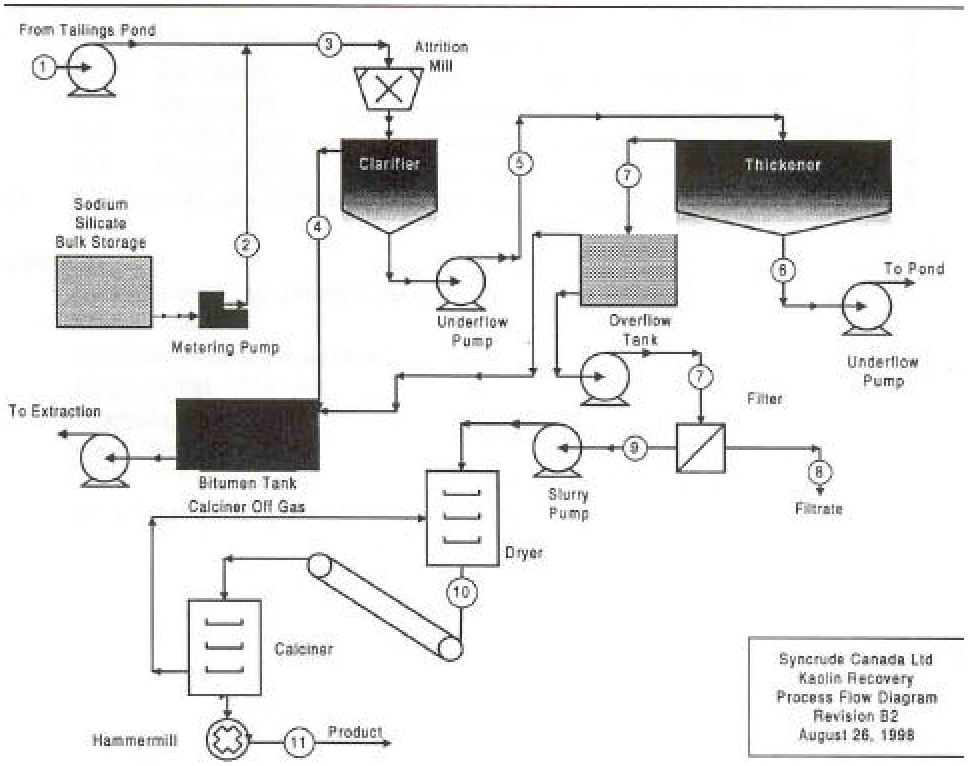

Figure 3: Tynebridge Extraction Process

INSA suggests that MFT be calcined without prior removal of the 2% bitumen typically contained in the raw tailings. This would reduce the requirement for additional fuel for the calcining process. In addition, INSA studies have shown that a benefit of this method in the material's performance in concrete.[21]

The MFT needs to be dried and calcined, a process that generates approximately 0.43 tonnes of CMFT per tonne of MFT[22].

INSA suggests that an existing multi-hearth furnace at Portland cement manufacturing plants could be used to calcine MFT on a pilot scale. A pilot-scale test of this nature will provide more realistic information for the commercial scale production than is currently available from laboratory scale operations.[23]

The optimum calcination temperature that produces the most reactive MK is in the range of 600-800^oC. One study found that calcination at 700^{o}C produced a MK that resulted in the highest concrete strengths. However, little difference in concrete strength was noticed when using MK calcined at temperatures up to 790^{o}C. Reactivity of the MK did reduce at a calcination temperature of 850^{o}C[24]. It is not clear whether these findings apply directly to CMFT, although another study has shown that MFT calcined at 1000^{o}C had very little pozzolanic activity[25].

[21] INSA, 2002.
[22] NKL, 2002, p. 5-3.
[23] INSA, 2002.
[24] Wong et.al., 2002, p. 6.
[25] Wong et.al., 2002, p. 8.

The oil and sands industry suggests that the advantages of producing CMFT for use in concrete instead of MK include: elimination of mining costs, availability of partially processed product, and use of vast quantities of waste product. This industry foresees transportation costs, capital investment, and market forces to be the main hurdles.[26]

4.2. Performance in Concrete as an SCM

Generally, MK improves most mechanical and durability properties of concrete, and thus, CMFT is expected to exhibit similar benefits. However, the properties of both MK and CMFT, and their performance in concrete, will be affected by the calcination temperature (see section 4.1).[27, 28]

To achieve the full benefits of using MK as an SCM in terms of improved concrete properties, INSA experience shows that MK must replace at least 15-20% of the cement, particularly when the material is not pure, as is the case with CMFT[29]. Wong et.al., 2002, suggest that replacement levels in excess of 15% for both MK and CMFT would be required for full removal of the calcium hydroxide formed during the hydration of cement[30].

The high specific area of MK relative to that of both Portland cement and fly ash increases the rate of concrete strength development. This property may be beneficial in a ternary blend of Portland cement, FA and MK, where the use of FA typically results in lower rates of strength development. The drawback of this feature of MK is that it also increases the water demand and the consumption of air-entraining agent, and reduces the workability of concrete[31, 32]. Furthermore, to counteract the detrimental effects of increased water demand, chemical admixtures (water reducing admixtures and/or superplasticizers) may need to be introduced, thereby increasing the costs of a concrete mix[33]. Additional work is required to ascertain these properties for CMFT, since it is a somewhat different material from pure MK. For example, one study showed that the specific surface of CMFT was nearly 2.5 times that of pure MK[34].

MK has historically been used in similar concrete applications with similar performance results as silica fume (SF). CANMET study has shown that MK concrete may require less superplasticizer and have slightly better constructability characteristics (e.g., finishability) than SF concrete[35]. However, Wong et.al., 2002, indicate that research into CMFT usage as a pozzolan is still in its infancy[36].

The NLK study suggests that by replacing a portion of the cement in a concrete mix with MK, the total cementitious material content can be reduced, thereby reducing the economic impact of using this high-priced SCM on the price of the concrete mix[37]. While this may be a feasible option for pure MK, which has a pozzolanic reactivity of

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[26] Ted Lord, Syncrude, January2003.
[27] Benoit Fournier, CANMET October 2001 presentation of Zhang and Malhotra, 1995 results.
[28] University of Calgary and Syncrude, October 2001.
[29] INSA, 2002.
[30] Wong et.al., 2002, p. 3.
[31] NLK, 2002, p. 4-5 to 4-6, and 4-8.
[32] Wong et.al., 2002, p. 2.
[33] AMEC, 2003.
[34] University of Calgary and Syncrude, October 2001.
[35] Benoit Fournier, CANMET presentation of Zhang and Malhotra, 1995 results.
[36] Wong et.al., 2002, p. 9.
[37] NLK, 2002, p. 4-9

1.15 compared to Portland cement[38], INSA does not recommend this approach, especially without concrete trial tests[39]. Furthermore, as indicated in Section 3.1, CMFT are only 85-90% as efficient as pure MK, bringing their pozzolanic reactivity down to the Portland cement level.

Colour is also an issue: unlike pure MK, which is almost white, CMFT is medium to dark grey, depending on the extent of carbonation, since the material becomes lighter with the increasing calcination temperature[40]. The whiter the MK, the more valuable it is, and the easier its introduction in the concrete industry[41].

Other properties that tend to improve when MK is used include: resistance to sulphate attack and alkali-silica reaction (ASR)[42], durability under freezing and thawing conditions, and resistance to cracking and surface deterioration[43].

5. Economic Evaluation

5.1. Cost of Production of CMFT

5.1.1. Cost of Extraction of MFT

Syncrude is currently involved in a consortium conducting a three-year research study between the oil sands operators, the University of Alberta and CANMET in Devon, Alberta. This research is focused on the extraction of commercial grades of MFT-kaolin as a value added resource. The study, which will demonstrate the technical and economic feasibility of this process, will cost approximately $250,000.

5.2. Cost of Testing CMFT for Use as SCM

CANMET is often involved in testing of new materials for use in concrete. They estimate that a study to optimize the MK content in concrete with respect to strength and cost of concrete would cost in the order of $30,000. A performance-testing program at CANMET of CMFT as an SCM in concrete was estimated to last approximately a year and a half and cost in the order of $200,000.[44]

5.3. Cost of Transportation

Remoteness of the Alberta oil sands is another major challenge for developing the CMFT as an SCM for use in concrete. The NLK study indicates that transportation costs from the production site at Fort McMurray to the market may range from $90 to $120 per tonne of CMFT, depending on the size of production, total transport distance, and availability of bulk transport[45]. This alone represents a major disadvantage for CMFT compared to PC, which is typically produced near the market, or FA, which is produced in the Edmonton region. FA also has a developed market, which allows the users to take advantage of bulk transport. The distances between Fort McMurray and potential

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[38] AMEC, 2003.
[39] INSA, 2002.
[40] Figure in January 22, 2001 letter from George Jones
[41] INSA, 2002.
[42] Wong et.al., 2002, p.1
[43] NLK, 2002, p. 4-6 and 4-7.
[44] Personal Communication, Nabil Bouzoubaâ, CANMET, July 10, 2003.
[45] NLK, 2002, p. 3-4.

markets (including off shore markets) for CMFT as an SCM in concrete are illustrated on Figure 4.

Figure 4: Distances between Production Site and Potential Market for CMFT

5.4. Demand vs. Cost vs. Price

The EcoSmart initiative on this source of MK has furthered the understanding of the circular relationship between the demand, the cost and the price of CMFT. This point is best illustrated by Figure 5 and Table 2.

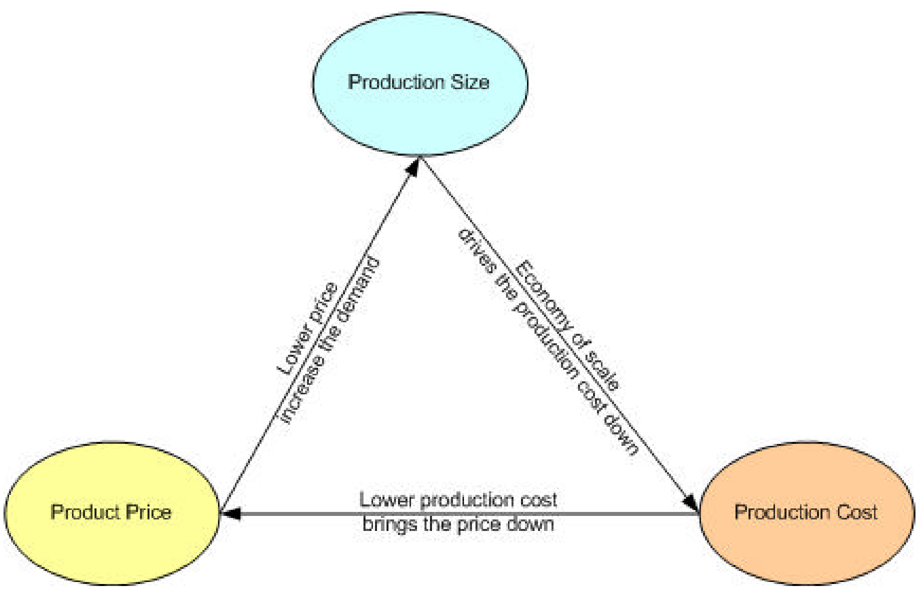

Figure 5: Relationship between Demand, Cost and Price of CMFT

Figure 5 demonstrates that Production Size (Supply) determines the Cost; the Cost of production with the desired rate of return on investment plus transportation cost determine the Price; and the Price of the product determines the size of the market, or the Demand. However, in the end, the Demand drives the Supply, sets the Price, and ultimately determines the Cost. If the Cost relative to the Price returns a favourable interest on the investment, the feasibility of a venture is determined. The producer (in this case either the oil sands industry or a third party) then decides if the rate of return meets their expectations. Indeed, the ultimate variable in this "equation" – whether to proceed with the venture or not – is the producer's willingness and desire to take the risk of making the initial investment. Table 2 presents several options for CMFT production based on the NLK and Tynebridge studies.

Table 2: Relationship between Demand, Supply, Cost and Price of CMFT

Relative Size of CMFT Production Plant	Demand (tonnes / year)	Supply (tonnes / year)	Cost ($ / tonne)	Price* ($ / tonne)
N/A	0	N/A	N/A	650-680 (current price of MK)
Smallest (Tynebridge)	0	22,000	167	600
Smallest (NLK)	20-24,000	37,000	114	303
Medium	39,000	74,000	72	282
Large (based on a given Price that sets the Demand)	200,000	N/A	N/A	130
Large (based on a given Supply that determines the Price)	N/A	1,000,000	29	142

* Includes transportation costs, assuming delivery within Western Canada and North-Western States

In summary, at the current price of MK ($650-680/tonne, which is comparable to the price of silica fume) the demand for CMFT is virtually nil. There are four main reasons for this:

1. the product is inferior to MK in its properties as an SCM, including its colour,
2. the demand for high-performance, white MK as an SCM is presently small and the supply of pure MK is sufficient to meet the current demand,
3. the price in the best case scenario would be similar to Portland cement and higher than FA, and
4. if CMFT aims to supply the demand for lower grade SCM, it cannot compete against FA, which can be produced at near zero cost, without additional processing, closer to the market, and with negligible environmental impact associated only with its transportation.

At the $600/tonne price level as determined by the Tynebridge study for 22,000 tonnes of CMFT supply annually, the demand can be assumed to be nil as well (for the same reasons as above).

The NLK study calculates the price of $303/tonne for the production of 37,000 tonnes/year. The demand at this price within Western Canada by the concrete industry is estimated at 20-24,000 tonnes. At the slightly lower price of $282/tonne when production is doubled to 74,000 tonnes/year, the demand is estimated to increase to only 39,000 tonnes/year. The balance of the supply would need to find other markets (e.g., paper, tires, etc.) or the geographical market would have to be expanded (but this carries additional transportation cost implications).

A production level of 1,000,000 tonnes/year lowers the price of CMFT to $142/tonne. This production level assumes an extensive market for CMFT, both in the type of application and geographical extent.

Since MK is currently used only in specialty concrete products, such as ultra strength concrete, the price of MK is relatively very high and the market for MK is relatively small. To create a large enough demand to keep the cost down and make the venture profitable for a producer, the price of CMFT for use in concrete will have to be at most at the level of Portland cement, if not lower. In Western Canada, the price of CMFT would have to be at most $130/tonne. Therefore, based on a market analysis curve provided by the NLK study in Figure 6, this price is expected to generate a demand for 200,000 tonnes/year. Detailed assumptions for these numbers may be found directly in the two studies referenced.

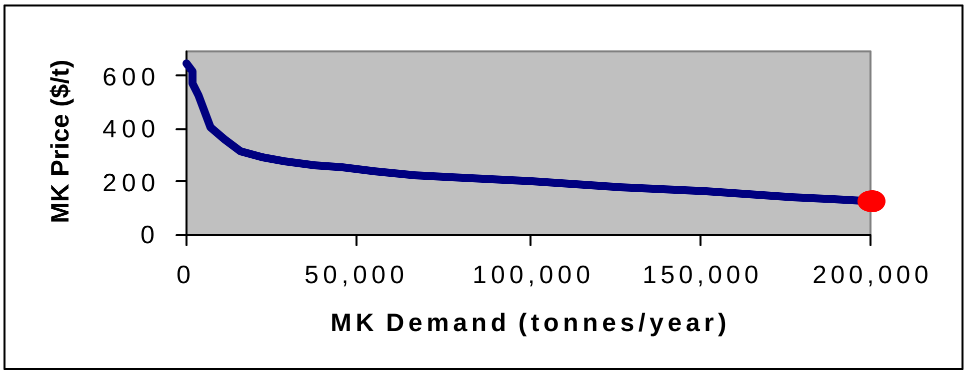

Figure 6: Market Analysis Curve: Price vs. Demand[46]

In the best case scenario, with the demand for CMFT at 220,000 tonnes/year at the $130/tonne price comparable to PC in Western Canada, extraction of the corresponding amount of MFT from the tailings ponds (approximately 11 million tonnes of tailings, assuming tailings contain 10% clay, of which about 20% could be converted to CMFT[47]) would not satisfy the need of the oil sand operators to clean up their tailings ponds. As indicated in Section 3, there is potential to produce 6 million tonnes of CMFT per year. The current SCM market could absorb a maximum of 220,000 tonnes of CMFT per year, much less than the 6 million tonnes that could be produced.

The lower reactivity and darker colour of CMFT than of MK makes the value of CMFT more comparable with that of FA. However, CMFT cannot compete with FA for the following reasons:

- the production of FA in Alberta already exceeds the demand,
- the price of FA (FOB) at a power plant in Alberta is low (from $8 - $12 / tonne),
- FA does not require additional processing,
- FA is closer to the market, and
- the GHG benefit in concrete is greater with FA.

[46] NLK, 2002, p. 2-9.
[47] NLK, 2002, p. 4-3.

The use of yet another SCM by the ready-mixed concrete supplier requires additional cost for a separate silo for CMFT.

Therefore, unless drastic change occurs in the current price or quality of FA, CMFT will have difficulty penetrating the SCM market.

6. Environmental Evaluation

The NLK report calculated the CO_2 impact of using CMFT as an additional SCM in a concrete mixture containing 300 kg/m^3 total cementitious materials content and 25% fly ash (by weight), i.e., Portland cement at 225 kg/m^3 and fly ash at 75 kg/m^3. NLK suggested that by using CMFT as an additional SCM, the total cementitious materials content could be reduced by up to 10%. However, the validity of this approach is questioned by INSA[48].

As an example, the CO_2 signature of concrete would be decreased by amounts in the order of 0.08-0.20 tonnes/m^3 of concrete as a result of using 10% CMFT (by weight) in the concrete mixture, for total cementitious materials contents reductions of 0-10%, respectively[49]. This reduction may be compared with the CO_2 signature reduction of 0.13 tonnes per cubic meter of concrete when cement is replaced by an additional 10% fly ash (i.e., in addition to the 25% already replaced in the baseline mix). Therefore, it is evident that unless the total cementitious materials content is reduced (by at least 6%, according to these calculations), there is no CO_2 advantage to using CMFT.

The NLK analysis assumes that 0.9 tonnes of CO_2 are generated per tonne of Portland cement produced, and that the CO_2 emissions associated with the production of fly ash are accounted for by the power generation sector, thus, only transportation-related CO_2 emissions need to be considered. The study calculated that 0.37 tonnes of CO_2 would be generated per tonne of CMFT produced, and that transportation-related CO_2 emissions would be in the order of 0.02 tonnes per tonne of CMFT delivered to the Vancouver market[50]. The transportation emissions can be assumed to be roughly the same for CMFT and FA transported from northern Alberta to south-western British Columbia.

Other environmental benefits of developing CMFT from the oil sands industry include:

- reduction of the volume of the tailings ponds;
- improved settling properties of tailings ponds for process water recovery; and
- improved oil recovery efficiency from the tar sands (if the 2% residual bitumen is recovered from the tailings)[51].

Some of the detrimental environmental impacts of this initiative include:

- additional natural gas requirements for the calcination and drying processes (note: CO_2 emissions from the burning of this fuel have already been incorporated in the calculations of the CO_2 signature of concrete containing CMFT);
- some additional emissions of other contaminants from the calcination and drying processes, e.g., CO, NO_x, N_2O, SO_2, CH_4, PM (filterable);
- emissions from transportation of CMFT from source to user (note: CO_2 emissions from the transportation of this material have also already been included in the CO_2 signature of CMFT concrete)[52].

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[48] INSA, 2002.
[49] NLK, 2002, based on data used to generated graph on p. 5-9.
[50] NLK, 2002, p. 5-10.
[51] NLK, 2002, p. 5-9 and 5-10.

7. Summary of Findings

7.1. Properties of Various SCMs and PC

Examination of the various aspects of CMFT extraction, processing, and potential use as an SCM in concrete can be summarized and the properties compared with those of other SCMs and PC. Table 3 presents a summary of the main aspects that can be used for comparison.

Table 3: Comparison of the Properties of Various SCMs and PC

Property	CMFT	MK	SF	FA	PC
Performance Factor (approximate reactivity relative to PC)[(a)]	1.10	1.15	1.25	0.85	1.00
Colour	Medium to Dark	White	Dark	Light to Medium	Medium
Cost in BC (on the market) ($ / tonne of product)	(unknown)	$400 - $600	$400 - $600	$8 (at the Alberta plant) $75 (with transport)	$130-$150
Availability (in Canada) (tonnes/year)	***Potentially:*** 6 million[53] ***Currently:*** for small laboratory tests only	(unknown, but abundant)	20,000[54]	2,200,000[55]	14,000,000 capacity
CO_2 Generated by Production (tonnes CO_2 / tonne of product)	0.37	0 [(b)]	0	0	0.9
CO_2 Saved by Partial Replacement of PC (tonnes CO_2 / tonne of product)	0.53 (0.37-0.9)	0.9	0.9	0.9	N/A
CO_2 Saved by Partial Replacement of PC (tonnes CO_2 / m^3 of concrete)	0.08-0.20[(c)]	0.13	0.13	0.13[(d)]	N/A

[(a)] Factors used in the work by Popovic[56]
[(b)] Emissions attributed to mining industry
[(c)] 10% CMFT in addition to 25% FA, total cementitious material content reductions by 0-10%[57]
[(d)] Additional 10% FA in addition to 25% FA

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[52] NLK, 2002, p. 5-10.
[53] NLK, 2002, p. 4-3.
[54] Bouzoubaâ and Fournier, 2003, p. 31.
[55] Bouzoubaâ and Fournier, 2003, p. 31.
[56] AMEC, 2003.
[57] NLK, 2002, based on data used to generated graph on p. 5-9.

7.2. Benefits of CMFT Production and Usage as SCM

It has been shown that it is technically feasible to produce CMFT from the oil sands tailings ponds. The benefits associated with the production of CMFT and its use as an SCM in concrete include:

- extracting MFT from tailing ponds would allow oil sands operators to recover the limited process water, reduce the size of the tailings ponds, increase the capacity of the tailings ponds for future operations, and reduce the risk of a breach in the banks containing the tailings ponds;
- the use of this by-product would displace the need for mining virgin material;
- there are huge reserves of this by-product in Canada; and
- use of CMFT as an SCM in concrete has GHG reduction potential.

7.3. Drawbacks of CMFT Production and Usage as SCM

The drawbacks associated with the production of CMFT from oil sands operations and its use as an SCM in concrete include:

- CMFT is not the same as MK;
- the performance of CMFT as an SCM is inferior to that of MK, rather, it is more comparable to FA;
- CMFT is a low-value product due to its dark colour;
- the transportation costs are high;
- capital investment is needed to initiate commercial production;
- the resistance of the construction industry needs to be overcome;
- CMFT cannot compete against fly ash; and
- the current SCM market is not large enough to generate the economies of scale required to keep the price down.

8. Conclusions

8.1. General

Calcined mature fine tailings (CMFT) are a material with similar but inferior properties to pure metakaolin (MK).

CMFT is dark in colour, which makes it a low-value product in most of the potential markets identified to date (e.g., white concrete products, paper). It is less reactive than pure MK (85-90% effectiveness), approximately as reactive as Portland cement, and only somewhat more reactive than fly ash (FA) (18% more reactive). It is more energy and labour intensive to produce than FA, where both materials are by-products of industrial processes. Its energy intensity also makes CMFT less environmentally beneficial than FA. Finally, under current market conditions, CMFT is at least four times more expensive than FA.

The demand for MK, particularly CMFT, in Western Canada is not sufficient to justify the capital expense of developing this SCM. However, the worldwide demand for SF and the insufficient supply may provide the market needed to economically develop CMFT.[58]

Additional research into the use of MK, and more specifically CMFT, is required to determine the optimum temperature for calcination, the long-term performance in

[58] Personal Communication, Phil Seabrook, Levelton, September 19, 2001. Comments on NLK, 2002 report.

concrete, and quality control requirements and procedures[59]. Also, more information is needed for the ready-mixed concrete producer as the user of CMFT, such as the price, availability, additional testing requirements, risk management options, etc.[60]

8.2. Oil Sands Industry

The oil sands industry is not interested in going into this venture if there is no identifiable market for the CMFT product[61]. Their main interest presently lies in recovering the process water for reuse in the operations. If the water recovery process generates a concentrated and practical MFT as a by-product, it would be made available for further processing by an interested third party. They consider production of CMFT as a synergistic approach to fine tailings management, water recovery, environmental protection, and waste product commercialization[62].

The oil sands industry is interested in producing a new batch of MFT (uncalcined, calcined, or partially calcined) for testing at a laboratory, such as CANMET, and for experimenting at an interested ready-mixed plant.

8.3. Cement/Concrete Industry

The cement and concrete industry are not presently interested in taking on the development of CMFT as an SCM. They would be willing to consider using CMFT if the oil sands industry can provide the product at no cost at their plants. This industry also raised the concern that presently there is no market for this material in concrete applications or the ready-mixed concrete industry, and that the investments required to make MK a viable SCM could be better spent elsewhere to reduce the CO_2 footprint of concrete[63, 64, 65]. In addition, as was the experience with developing FA as an SCM, specifiers and end users would have to be persuaded of the benefits of CMFT and would have to be willing to accept any associated risks. As a rule, most Canadian industry specifiers defer to CSA specifications when designing their projects. As such, there may be a further hesitance to use MFT-based metakaolin, as it is not derived from a pure natural kaolinite clay source[66].

8.4. EcoSmart Concrete Project

The EcoSmart Concrete Project has ascertained that producing CMFT from the oil sands industry is feasible, provided that all MK markets can absorb this product, including the concrete, paper, tire, etc. markets. However, based on its mandate, EcoSmart's focus is only on the SCM application, and EcoSmart may revisit this application pending the outcome of the investigation of the oil sands industry into other applications.

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[59] University of Calgary and Syncrude, October 2001.
[60] Personal Communication, Phil Seabrook, Levelton, September 19, 2001. Comments on NLK, 2002 report.
[61] John Oxenford, Syncrude, January 14,2003.
[62] Ted Lord, Syncrude, January 2003.
[63] Personal Communication, Jim Caruth, Pozzolanic, October 11, 2001. Comments on NLK, 2002 report.
[64] Personal Communication, Ron Sills, Lehigh Inland Cement, October 11, 2001. Comments on NLK, 2002 report.
[65] Personal Communication, Tom Gibson, Lehigh Northwest Cement, September 23, 2001. Comments on NLK, 2002 report.
[66] Personal Communication, Paul Masson, Lafarge Canada, January 14, 2003. Metakaolin meeting.

9. Future Work

9.1. EcoSmart

Based on the findings in this study, it is recommended that no further work be done by the EcoSmart™ Concrete Project on developing CMFT as an SCM at this time. When an improved and feasible product is developed by the oils sands industry and research community, it is recommended that EcoSmart initiate a case study project using this material.

9.2. Research Community

CANMET, the University of Alberta, the University of Calgary, and other interested parties are continuing their research work on the extraction of this source of kaolin. It is also recommended that research be continued on the use of CMFT in concrete, to bring the knowledge about the performance of CMFT to the level of other SCMs such as FA, SF and MK. The oil sands industry should provide samples as required.

9.3. Oil Sands Industry

The oil sands industry is continuing to investigate economical ways to clean up the tailings ponds, and conducting research into the extraction of quality kaolin that could be used to produce quality CMFT, comparable to pure MK. Other uses for the MFT and CMFT will be investigated, along with continuation of investigations into other third party groups interested in producing CMFT. The oil sands industry will also try to find a way to reuse the process water from the tailings ponds instead of continually drawing on fresh water and increasing the size of the tailings ponds. This study will be completed by 2005.

9.4. Concrete Industry

Once successful results from the oils sands industry are established, the ready-mixed concrete producers should experiment with CMFT in concrete and gain confidence in the use of this SCM. The oil sands industry should provide sufficient samples to the ready-mixed concrete producers for testing. It is further recommended that the concrete industry adopt this material as an alternate SCM once the oil sands industry and the research community have advanced the knowledge and quality of this material.

10. References

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11. Appendices

The appendices to this report are prepared separately from this document, and are available at www.ecosmart.ca.

Appendix 1: AMEC Earth & Environmental Limited (Rusty Morgan). “Metakaolin Review Meeting Edmonton – January 14, 2003: Summary of Presentation.”

Appendix 2: Bouzoubaâ, N. and Fournier, B. "Current Situation of Supplementary Cementitious Materials (SCMs) in Canada." CANMET Report MTL 2003-4 (TR), Natural Resources Canada, Ottawa, April 2003.

Appendix 3: EcoSmart Concrete Project, Minutes of Metakaolin Meeting in Edmonton, October 16, 2001.

Appendix 4: EcoSmart Concrete Project. Minutes of Metakaolin Meeting in Edmonton, January 14, 2003

Appendix 5: Fournier, B. Program Manager, Concrete Technology Program, CANADA. “Presentation of Zhang and Malhotra, 1995 Results”, EcoSmart™ Metakaolin Meeting, Edmonton – October 16, 2001.

Appendix 6: INSA (Pera, Jean). "Analysis of the NLK Project EA 2860 – EcoSmart™ Concrete Project Metakaolin Pre-Feasibility Study." December 2002.

Appendix 7: Lord, Ted. Syncrude Canada. Presentation on "Kaolin Clay Derived from Oil Sands Fine Tailings – The Syncrude Perspective" to EcoSmart at Metakaolin Stakeholder Meeting in Edmonton, Alberta, January 14, 2003.

Appendix 8: NLK Consultants Inc. "EcoSmart Concrete Project Metakaolin Pre-Feasibility Study." September 2002.

Appendix 9: Omotoso, D., Hamza, H., Oliver, J. and Lord, T. Presentation by CANMET AST, Devon, Alberta Research Council, and Syncrude Research on "Kaolin in Oil Sand Tailings" to EcoSmart at Metakaolin Stakeholder Meeting in Edmonton, Alberta, October 16, 2001.

Appendix 10: Tynebridge Technologies Limited. "Syncrude Kaolin Recovery Project." September 1998.

Appendix 11: University of Calgary and Syncrude Canada. Research Update Presentation on "Potential Use of Metakaolin from Oil Sand Tailing in Concrete." October 16, 2001.

Appendix 12: Wong, R.C.K., Gillott, J.E., Thomas, M.J., and Poon, C.S. "Calcined Oil Sands Tailings as a Pozzolanic Admixture for Concrete." Submitted to Cement and Concrete Research for publication in November 2002.