Investigating 21st Century Cement Production in Interior Alaska Using Alaskan Resources

Funded by the
Fairbanks North Star Borough

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Abstract

High performance geopolymer cements are used commercially elsewhere in the world due to superior performance to portland cement. These cements are stronger, fireproof, and waterproof. They bond strongly to most materials, do not appreciably expand or contract, are foamy, and resistant to salts, acids and alkalis. They also require less energy to make and are more environmentally benign. Additionally, geopolymer cement can be produced in ways that make it useful for addressing a range of everyday and extreme challenges.

Through this grant and related work, CCHRC has investigated the potential for producing geopolymer cements using local materials and making products for the Alaskan marketplace. Based on this review, CCHRC is optimistic about the chance for a commercially viable enterprise to develop. Compounding our optimism is the potential for a new geopolymer industry to create local jobs and economic opportunities, wisely use Alaskan resources such as fly ash and mine tailings, make products that help address the extreme challenges of our geographical setting, and significantly reduce CO$_2$ emissions associated with cement manufacturing.

Geopolymers require 30-60% less energy to make and release about 80% less carbon dioxide into the atmosphere. Unlike portland cement, which requires a huge plant costing upwards of $150 million to manufacture, geopolymer cement production requires only a concrete batch plant costing between $50,000 and $200,000. In part, this is because the source materials for geopolymers are by-products that have already gone through combustion in a power plant, or milling in a mine, which are processes analogous to transforming limestone into portland cement clinker.

Five coal-fired electrical power generation plants in Interior Alaska are currently producing more than 100,000 tons of ash per year. The Fort Knox gold mine has more than 200 million tons of finely milled tailings accumulated in their retention pond. These pre-processed materials can be used to locally manufacture geopolymer cement, concrete and derivative products.

This project has demonstrated that fly ash from GVEA’s Healy 1 power plant and from Aurora Energy’s Chena power plant both work as the sole active alumina-silicate source for producing geopolymer cements. Fort Knox mine tailings are demonstrated to be a useful filler material and further experimentation may confirm their potential as an active component.

The cost of producing geopolymer cement-based concrete in Fairbanks, Alaska, is approximately the same as the cost of producing portland cement-based concrete in Fairbanks at current material prices. The material cost for both is approximately $84 per cubic yard. The processing equipment and costs are the same. The higher the concrete’s performance specifications are set, the more cost advantageous using geopolymer cement becomes.

This project has moved Fairbanks significantly closer to being ready to utilize local resources presently wasted to commercially manufacture geopolymer cements, concrete and derivative products on an economically competitive basis.
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Project Description

This project was undertaken to investigate and foster local manufacturing of cement and cement products using locally available resources. The cements investigated are known as “geopolymers” or “alkali-activated alumina-silicates.” The fundamental chemistry and molecular structure of geopolymers are significantly different from portland cement.

Geopolymers are relatively new cements that have been developed and are commercially available elsewhere in the world. Geopolymers are substantially superior to portland cement in all performance measurements. These cements are stronger, fireproof, and waterproof. They bond strongly to most materials, do not appreciably expand or contract, are foamable, and resistant to salts, acids and alkalis. They also require less energy to make and are more environmentally benign.

Concrete is, and will continue to be, a vital component of the infrastructure upon which modern economies are based. About three tons per human on earth are manufactured every year and global demand continues to increase. Concrete is made from locally available sand and gravel bound together by cement. For the last century the cement used has been predominantly portland cement made from limestone. The production of every ton of portland cement releases about a ton of carbon dioxide into the atmosphere and consumes the energy equivalent of 450 lbs of coal. All of the concrete in Alaska is made using portland cement imported from Outside, mostly from Korea. Imported portland cement is costly and has bearing on project economics for which cement is required. This is especially prescient in remote areas and large projects.

Funded by the Fairbanks North Star Borough, this project was built upon CCHRC’s substantial investment researching and experimenting with modern cements over the past three years. This early research determined that the performance characteristics of these cements make them well-suited for creating high-performance products which could resolve many existing housing problems in cold climates, while reducing environmental impacts. CCHRC has focused on investigating how geopolymers can be made using raw materials readily available in Alaska, including ash from coal-fired electrical generation plants, mine tailings and naturally occurring materials such as clay and glacial silt. CCHRC’s base of knowledge and empirical test results provided a strong foundation for this project. Central to CCHRC’s mission and strategic plan is to work with private manufacturing companies to help develop superior products. This project established and provided the foundation for expanding the collaborative relationships between the University of Alaska Fairbanks (UAF), non-profit, for-profit, and public corporations that will be necessary to accomplish the work necessary to bring locally produced geopolymer cement products to a willing market.
Accomplishments

Development of presentations:

Two PowerPoint presentations were developed and used to introduce the potential for producing geopolymer cement and cement products in Fairbanks. The first, “Producing Geopolymers in Interior Alaska” (Appendix A), is intended for a general audience. The second, “Alaskan Geopolymer Costs” (Appendix B), is intended for those interested primarily in the economic competitiveness of geopolymer cement compared to portland cement.

Development of prototype mix designs:

Through experimentation, several successful mix designs have been developed using fly ash from GVEA’s Healy 1 power plant in Healy and Aurora Energy’s Chena power plant in Fairbanks. Some of the most successful mixes also include tailings from the Fort Knox gold mine. These mixes use soda or potassium hydroxide and sodium silicate as the alkali-activator and small amounts of other additives commonly used in cements such as superplasticizers and set retarders.

Analysis of locally available raw materials which are potentially suitable:

Whether or not a raw material is suitable for making geopolymer cement depends primarily upon three factors: it’s silica content; it’s alumina content; and the reactivity of the two. In simplified and practical terms, for a given alumina-silicate material, this boils down to answering the questions: 1) does it contain a significant amount of alumina?; and 2) are the particles small enough, or the molecular structure amorphous enough, that they are partially soluble in a strongly alkaline solution? If the answer to both is yes, then the material may be suitable as a primary component for making geopolymer cement. If the answer to only one is yes and the other no, then the material may still be useful, but not without some additional alumina-silicate source.

To determine their chemical makeup, X-ray fluorescence (XRF) analysis was conducted by Ken Severin at UAF’s Advanced Instrumentation Laboratory on several fine particulate alumina-silicate materials readily available in the Interior. These included fly ash from the Healy 1, Aurora and UAF power plants, Fort Knox and Pogo mine tailings, and three sources of silt. Analysis was also done on samples of some naturally occurring clay from Healy, Hinkley Gulch, Livengood, Murphy Dome, Silver Fox and the Taylor Highway provided courtesy of chemist and potter David Stannard. Metakaolin (calcined kaolin clay), which is most commonly used for producing geopolymers in the laboratory, was included in the analysis for reference. The graphical representation of the XRF results is provided in Appendix E.
Additionally, UAF’s Advanced Instrumentation Laboratory performed a particle size distribution analysis on the same set of samples. A graphical representation of the results is provided in Appendix E.

Experimental and analysis results indicate that all of these materials are potentially useful for producing geopolymer cements. Since CCHRC’s efforts to date have focused upon the most readily available materials, the natural clay that would require quarry development have not yet been investigated. Of the rest, only the fly ashes have been demonstrated to work as the sole active alumina-silicate source for geopolymer cement production. The Fort Knox mine tailings have proven to be a useful filler material and further experimentation may determine their potential as an active component.

Likewise, Chena river mud, which has the finest particle size of the local silts sampled, may be useful either for making geopolymers that require some heat to cure, or after calcining to increase their reactivity. Calcining, in this case, involves heating the silt in a kiln to approximately 1400°F for about 30 minutes.

Collaboration with Aurora Energy, LLC:

Aurora Energy, LLC, owned by Usibelli Coal Mine, Inc., owns and operates the coal-fired electrical power generation plant located on the Chena River in downtown Fairbanks. Like all coal-burning companies, Aurora Energy is facing a significant increase to their operating costs. The US Environmental Protection Agency (EPA) will likely soon reclassify fly ash as a hazardous waste. This will mean that instead of being cheaply disposed of as a benign fill material, the ash will be isolated in a hazardous waste disposal facility. Therefore, Aurora Energy, Usibelli and other coal providers and users are seeking more economically beneficial alternatives.

The most common use of fly ash around the world is as a supplemental cementitious material (SCM), added to portland cement and/or concrete to improve its physical properties and decrease cost. This use of fly ash from Alaskan coal is more complicated than using ash from most of the rest of the United States due to its higher calcium content. Aurora Energy’s fly ash, and ash from similar power plants, has the additional problem of containing too much un-burnt carbon to meet the standards required for use in portland cement mixes. The excess carbon interferes with the chemical admixtures, particularly for air entrainment necessary for freeze-thaw endurance. This degrades the performance of the concrete.

In areas with denser populations and greater volumes of fly ash, the removal and recycling of carbon from fly ash is economically viable. That does not appear to be the case here in Alaska.

These issues, combined with a commitment to economic development in their local community, have led the Usibelli and Aurora Energy management teams to take an active leadership role in investigating the potentials for using fly ash for the production
of geopolymer cement. As a direct result of this FNSB-funded project, Aurora Energy is working closely with CCHRC to continue this investigation with the goal of involving additional private companies this spring and summer. CCHRC is grateful to and encouraged by Aurora Energy and most especially CEO Buki Wright’s enthusiastic interest and funding support.

Collaboration with UAF School of Management:

Associate professor Jim Collins, UAF School of Management Director of Entrepreneurship, has taken an interest in this project and begun involving some of his students in working on the economic feasibility and business-planning aspects. This project provides students with an excellent opportunity to leverage their academic study and exercises into real-world results. CCHRC is pleased and grateful to have the opportunity to collaborate with these students and for Dr. Collins’ interest and mentorship.

Collaboration with Small Businesses in Fairbanks & North Pole:

A growing number of local cement-related business owners and managers are expressing interest in participating directly in CCHRC’s efforts to develop the commercial applications of geopolymer cements and concretes. These businesses presently include Stonecastle Masonry, Fairweather Masonry, MAPPA Test Lab, and Fairbanks Precast & Rebar.

One of the top 20 in the 2010 Arctic Innovation Competition:

Out of more than 200 entries in the UAF School of Management 2010 Arctic Innovation Competition, CCHRC’s presentation (given by Ty Keltner) on the potential for local geopolymer development was selected as one of the top 20. The final four projects were notably further along in the process of establishing a specific business. CCHRC’s involvement in the competition helped establish connections with individuals contributing suggestions and expressing interest in working with us in the future. These included Jim Collins in the School of Management and Shiva Hullavarad in the Advanced Materials Group of the UAF Institute of Northern Engineering.

Collection and organization of 2.5GB of relevant literature:

CCHRC staff have collected, organized and partially reviewed more than 2.5 GB of text on the alternatives to portland cement. That currently amounts to 2,049 files in 161 folders and seven mind-maps, including over 600 research papers. Plus seven text books on geopolymer cements. Although it is outside the scope of this project, the organization of this information has been done in a manner which will facilitate references, abstracts and CCHRC’s notes being made publically available on the Internet without copyright infringement. It is our hope that this extensive and on-going literature
search will help and encourage UAF graduate students to undertake master’s projects in support of local geopolymer production and use.

Development of a geopolymer research proposal to the National Science Foundation:

In 2009, as part of CCHRC’s on-going efforts to secure funding to expand and accelerate work toward the local geopolymer production, a proposal was developed and submitted to the National Science Foundation (NSF) Structural Materials and Mechanics program for $498,000, to be given over three years. Unfortunately, CCHRC’s proposal was not funded. That program did fund four other geopolymer projects totaling $800k.

CCHRC is presently working with faculty from the UAF Geological Engineering Program to revise, update and improve our previous proposal for re-submission to this year’s funding cycle to the same NSF program.

Preparatory work toward proposals to other public and private funding sources & collaborators:

This project has accomplished much of the preparatory work necessary for developing credible proposals to public agencies and private corporations likely to have a serious interest in its goals. These include the US Army Corp of Engineers, the Alaska Railroad Corporation and the Alaska Department of Transportation, among many others.
Next Steps Toward Geopolymer Production

Submit proposals to public and private funding sources and collaborators:

• Since the potential impacts of using geopolymer-based concretes for infrastructure such as dams, dikes, sea walls and armor blocks is so significant, the US Army Corps of Engineers should be one of the next agencies contacted.
• Presentations need to be given to the Alaska Railroad Corporation and the Alaska Department of Transportation to determine what work they would consider funding and the potential scope for geopolymer use in Alaska’s transportation infrastructure market.
• Similarly, presentations need to be given to private corporations such as Doyon, Ltd, NANA Regional Corporation, Eklutna, Inc. and others that are involved in large scale construction projects.
• Mining companies including Kinross (Fort Knox), Sumitomo (Pogo), Teck Cominco (Red Dog), Coeur Alaska (Kensington), The Pebble Partnership and Northern Dynasty Minerals (Pebble), need to be contacted regarding the potential for using mine tailings to produce geopolymers as well as the potential uses of geopolymers for at mines.
• Once the economic feasibility and Alaskan market potential have been sufficiently analyzed and collaborations with private corporations established, a proposal to the Alaska Industrial Development and Export Authority to facilitate capitalization would be in order.

Further economic feasibility analysis and business planning:

• For local geopolymer bulk concrete production;
• For local concrete railroad sleeper production;
• For local production of other specific concrete products.

Development and testing of geopolymer concrete mix designs:

• Using the cement and mortar mix designs developed thus far, produce concrete using a variety of locally available aggregates and test their performance characteristics. Further optimization of the geopolymer mix designs will be an on-going process.
• Continue working with local companies such as HC Redi-Mix and Alaska Precasters to ensure that the geopolymer concrete will be of commercial interest.

This work will be accomplished by CCHRC this spring in collaboration with and funded by Aurora Energy.

Investigation of other locally available alumina-silicate sources:
• Healy clay is worthy of special attention since it is already being removed as part of the overburden in the Usibelli Coal Mine operations. From geological investigations done in the past by the UAF Mineral Industry Research Laboratory, Healy clay is known to be high-quality kaolin clay. It may require little or no processing to be useful in geopolymer cement production.

• UAF’s Silver Fox clay, Tanana Valley loess and silts may decrease costs and open up possibilities for remote village geopolymer production.

Investigation of the alkali-activator sources:

• Gather more specific information regarding the possibilities for importing industrial quantities of dry sodium hydroxide and sodium (meta)silicate.

• Potential sources of alkalis to use instead of importing sodium or potassium hydroxide have not yet been investigated, but there are no obvious local alternatives. The predominant method for producing sodium hydroxide is through the electrolysis of salt from sea water. Thus, Alaskan production of sodium hydroxide could become economical only if the cost of electricity decreased dramatically as a result of, for example, a large hydro-electric dam being built. How the local production of geopolymer concrete would impact the engineering and cost of constructing such a dam is worthy of further investigation.

Preliminary product prototyping:

• Railroad sleepers
• Paving blocks
• Pervious pavements
• Refractory bricks
• Radiant floor slabs
• Floor, wall and ceiling tiles
• Counter tops
• Exterior wall sheathings, e.g., simulated rock, simulated wood, etc.
• Roofing shingles
• Retaining wall blocks
• Foamed/aerated insulating blocks
• Whatever local precasters want to try

Concrete and composite reinforcement evaluation:

• The performance characteristics of various reinforcing materials, when used in locally produced geopolymer concrete and composites, needs to be tested. This includes standard steel rebar, basalt rebar, chopped stainless steel wire, as well as polypropylene, nylon, glass, basalt, and refractory ceramic fibers.
Publicize and leverage the information collected by CCHRC:

- Transform the 21st century cement information collected by CCHRC into a world-class on-line compendium, nothing close to which is presently available from any institution working with geopolymer cements.

- Expand CCHRC’s 21st century cement library by acquiring copies of the subset of documents presently only referenced and make the entire collection available to UAF researchers and others through the CCHRC and Rasmuson libraries.

Intellectual property investigation and negotiation:

- At least three patents exist for high-calcium fly ash based geopolymer cements. How they will impact local production costs needs to be explored.

Further details and information regarding each of these project areas is available for discussion upon request.
Appendix A

Footnotes


More than 600 additional related bibliographical references available upon request.
Appendix B

Producing Geopolymers in Interior Alaska

(slide show)
“Promoting and advancing the development of healthy, durable, and sustainable shelter for Alaskans and other Circumpolar people.”
Geopolymers in Alaska

Presented by: Cole Sonafrank of the Cold Climate Housing Research Center

Location: 1000 Fairbanks Street, Fairbanks, AK 99708
Mail: P.O. Box 82489, Fairbanks, AK 99708
Phone: 907 - 450 - 1726
Email: cole@cchrc.org
Web: www.cchrc.org

At a meeting with the FNSB Mayor, April, 2011
About Cold Climate Housing Research Center

Promoting and advancing the development of healthy, durable, and sustainable shelter for Alaskans and other circumpolar people.

Founded October 1, 1999
About Cold Climate Housing Research Center

- Identify issues critical to creating shelter and related infrastructure for Circumpolar people
- Develop research projects to address these issues and initiate solutions
- Promote our findings
- Establish a product testing, development and certification program
- Stimulate local business enterprises
- Expand partnerships within the circumpolar north
Research and testing of Geopolymers and Magnesium Phosphate Cements at Cold Climate Housing Research Center since 2007
Ours is a Concrete Civilization

Concrete is used extensively for:

- Pavement
- Buildings
- Roads / bridges
- Pipes
- Footings
...and much, much more

Three tons are produced for every person on the planet per year and demand is increasing.
In 2007 China exported only 33 million tons of the 1.3 billion tons they produced.

Sources

Data from USGS 2006 & 2008 Mineral Commodity Cement Summaries:


Graphs from:
TheOilDrum.com

http://www.theoildrum.com/node/4162
What is Concrete?

- Cement (Binder)
- Sand (Fine Aggregate)
- Rock (Coarse Aggregate)
- Admixtures (Chemicals)
- Water

Batch Plant (Dry Mixing) → Mixer / Truck (Wet Mixing) → Concrete
Concrete is **Mostly Aggregate**

- Cement (Binder)
- Sand (Fine Aggregate)
- Rock (Coarse Aggregate)
- Admixtures (Chemicals)
- Water

**Batch Plant** (Dry Mixing) → **Concrete**

**Mixer / Truck** (Wet Mixing) → **Concrete**

*And the aggregate is about the same whatever cement is used*
Concrete is Cement Paste & Aggregate

Cement Paste + Aggregate = Concrete

Cement (Binder)
Admixtures (Chemicals)
Water

Sand* (Fine Aggregate)
Rock (Coarse Aggregate)

Concrete

*Mortar is cement paste and sand (no rock)
Ordinary Portland Cement (OPC) Paste

- Imported Manufactured Portland Cement
- Imported Admixtures
- Water

Portland Cement Paste
What is Portland Cement?

- Portland cement is a **hydraulic cement**, which means that water is an integral part of its chemical structure.

- Water makes portland cement easy to use.

- Portland cement’s water-based bonding is the root of its disadvantages.
What is Portland Cement?

Limestone, Clay and Gypsum  
(Minerals containing Calcium, Silicon, Aluminum and Iron)

Producing portland cement requires a huge manufacturing plant

Portland Cement

A portland cement Plant in Colton California
Disadvantages of Portland Cement

- Water absorption and expansion
- Premature deterioration requiring repair
- Poor performance in salty environments
- Damaged by fire
- Substantial CO$_2$ emissions during manufacturing
- All imported to Alaska (presently from Korea)
Emissions from Portland Cement Manufacturing

Creating one ton of Portland cement:

• Produces nearly one ton of CO$_2$
• Produces about 3 kg of NOX, an air contaminant that contributes to ground-level smog
• Produces about 0.4 kg of PM$_{10}$ – particulate matter that is harmful when inhaled
• Portland cement manufacturing accounts for about 8% of CO$_2$ emissions worldwide
Geopolymers* – Discovered in the 1950s

- **Alumina-Silicate**
  - Coal Fly Ash, Mine Tailings, Blast Furnace Slag, Clay, Silt, Loess etc.

- **Alkali-Activator**
  - Sodium Hydroxide
  - Sodium Silicate

- **Water**

  Requires only a simple batch plant

- **Geopolymer Cement**

* aka Alkali-Activated Alumino-silicate Cement
Geopolymers are Amorphous

Peter Duxon’s conceptual model for geopolymerization, J Mater Sci, 2007, 42:2819

Joseph Davidovits’ molecular models
“Alkali-activated binders have the potential to become the best and in many cases the most economical binder for routine construction and may evolve into a new generation of building materials.”
Current Geopolymer Product Manufactures

- Geopolymer Institute
- Geotree Technologies
- Rocla
- Zeobond
Advantages of Geopolymers

- Reduces the need for portland cement and enables a significant reduction in global CO$_2$ emissions as development occurs.
- Uses waste materials as the primary feedstock (e.g. fly ash, mine tailings, industrial chemical wastes).
- Reduces pollution and life-cycle costs.
- Increases the design life of infrastructure.
- Opens up opportunities for process and product improvements that take advantage of geopolymers’ unique properties.
Geopolymers
Novel to - and needed by - Alaska

- 80% less CO$_2$ emissions*
- 2 to 4 times stronger*
- More durable*
- More stable*
- Less permeable*
- Self-adherent
- Fire resistant to >1800°F
- Acid, base & salt resistant
- Blast & earthquake resistant

* Than Ordinary Portland Cement (OPC)

Geopolymer samples at CCHRC
## Binder Comparison

### Comparison of Typical Physical Characteristics
(Special mix designs will yield different results)

<table>
<thead>
<tr>
<th></th>
<th>OPC</th>
<th>MPCs</th>
<th>Geopolymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength in psi (Typical)</td>
<td>3,000 - 7,000</td>
<td>8,000 - 12,000</td>
<td>5,000 - 16,000</td>
</tr>
<tr>
<td>Bending Tensile Strength in psi</td>
<td>250 - 1,000</td>
<td>900 - 1700</td>
<td>300 - 2,900</td>
</tr>
<tr>
<td>pH Tolerance</td>
<td>6.5 to 14</td>
<td>3 to 11</td>
<td>3 to 14</td>
</tr>
<tr>
<td>Salt Tolerant (Continuous Exposure)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Max. Structural Temperature</td>
<td>1,500° F</td>
<td>2,300° F</td>
<td>2,000 - 2,700° F</td>
</tr>
<tr>
<td>Curing Time (Demolding)</td>
<td>1 - 2 Days</td>
<td>10 min - 2 hrs</td>
<td>3 hr - 3 days</td>
</tr>
<tr>
<td>Curing Time (High Strength)</td>
<td>28 days</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Curing Temperature Range</td>
<td>5° - 420° F</td>
<td>8° - 110° F</td>
<td>50° - 200° F</td>
</tr>
<tr>
<td>Bonds To Itself</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bonds To Reinforcement</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shrinks upon drying</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>0.0000012</td>
<td>0.00000017</td>
<td>~0.000001</td>
</tr>
<tr>
<td>Absorbs Water</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Foamable</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</table>

OPC is Ordinary Portland Cement  
MPCs are Magnesium Phosphate Cements  
Geopolymers are alkali activated aluminosilicates
The Cost of Concrete in Fairbanks

What does it cost to produce concrete in Fairbanks?

• What does concrete cost using portland cement?

• What would concrete cost using geopolymer cement?

• The short answers:
  Ÿ The costs are about the same for ordinary concrete
  Ÿ Geopolymer costs are less for high performance concrete
  Ÿ Using portland cement benefits someplace else
  Ÿ Using geopolymer cement benefits Fairbanks & Alaska
Modern* Portland Cement Pastes

- Imported Manufactured Portland Cement
- Imported Supplementary Cementitious Materials*
- Imported Admixtures (Expensive)
- Water

* Higher performance & durability than OPC

* SCM’s include fly ash, metakaolin, silica fume, slag, etc
Geopolymer* Cement Paste

- Local Alumina-Silicate Materials (Coal Fly Ash, Mine Tailings, Silt, Loess, etc.)
- Imported Admixtures & Alkali-Activator (Sodium Hydroxide + Sodium Silicate)
- Water

* aka Alkali-Activated Alumino-silicate Cement
Concrete Quality ~ Cost

Concrete Specification

Mix Design (How much of what to use):
- Type of Cement
- Types of Supplementary Cementitious Materials
- Type & size gradation of Aggregates
- Types of Admixtures
- Quantity of each component
- Water to cement ratio, slump, etc
- Types, sizes & placement of reinforcement

High Performance & Cost

Concrete Quality

 Ordinary - Low Cost

(Bridges) $$$
(Sidewalks) $
Portland Cement Concrete Cost*

Concrete Prescription Specification

Mix Design (How much of what to use):
- Type of Cement
- Types of Supplementary Cementitious Materials
- Type & size gradation of Aggregates
- Types of Admixtures
- Quantity of each component
- Water to cement ratio, slump, etc
- Types, sizes & placement of reinforcement

High Performance & Cost

(Portland Cement Concrete Quality)

Ordinary – Low Cost

*Bridges*

$200

*Sidewalks*

$84

* Per cubic yard in Fairbanks, Alaska 2010
Geopolymer Cement Concrete Cost*

Concrete Performance Specification

Mix Design (How much of what to use):
- Type of Cement
- Types of Supplementary Cementitious Materials
- Type & size gradation of Aggregates
- Types of Admixtures
- Quantity of each component
- Water to cement ratio, slump, etc
- Types, sizes & placement of reinforcement

High Performance & Cost
- Geopolymer Cement
- Concrete Quality
- (Bridges)
- Ordinary - Low Cost
- (Sidewalks)

$200
$84
$

Per cubic yard in Fairbanks, Alaska 2010

* COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC
## Concrete Material Cost Breakdown

<table>
<thead>
<tr>
<th>Material</th>
<th>Portland Cement Concrete</th>
<th>Geopolymer Cement Concrete</th>
</tr>
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<tbody>
<tr>
<td>Cement</td>
<td>$47.94 / yd³</td>
<td>$0.32 / yd³</td>
</tr>
<tr>
<td>Sand</td>
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* Per cubic yard in Fairbanks, Alaska 2010
* Not yet optimized for performance or cost
### Processing Costs*

*Processing Costs* are ~ the same

<table>
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<tr>
<th>Process</th>
<th>Portland Cement Concrete $ / yd$^3$</th>
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<td>same</td>
</tr>
<tr>
<td>Placing</td>
<td>same</td>
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</tr>
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<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Curing</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td><strong>$ per cubic yard</strong></td>
<td><strong>$ same</strong></td>
<td><strong>$ same</strong></td>
</tr>
</tbody>
</table>

*Per cubic yard in Fairbanks, Alaska 2010*
Using Alaskan Waste Materials

- **Ash** is the residue that remains after coal is burned
- **Fly Ash** is the by-product collected from the flue gases (think of it as cement)
- **Bottom ash** is the heavier and coarser by-product (think of it as aggregate)

- Roughly **300 tons of ash per day** are produced in the Fairbanks area
Alaskan Fly Ash

Fly Ash

Fly ash is microscopic spheres comprised of many metal oxides, but is mostly silica (SiO$_2$) and some alumina (Al$_2$O$_3$).

Other components vary with percentages of less than 30% total.

Alaskan coal produces ash that contains much more calcium than most ash elsewhere. That makes using it for geopolymer cement different, but it works.
Alaskan Resources – Not Wastes

Mine Tailings - Benign

Alaskan mines, like Fort Knox and Pogo, produce benign waste that still must be contained and monitored. They are a liability.

These tailings are predominantly finely-milled quartz, the result of extensive and expensive grinding.

This material makes good fill for geopolymers and other cements and possibly an active component.

More than 200 million tons of finely milled tailings are available in the Fort Knox gold mine retention pond.
Alaskan Wastes – From Bad to Good

Mine Tailings - Hazardous

One purpose of geopolymer development is the encapsulation of hazardous, radioactive and contaminated materials within an impervious, high strength material.

Tailings from Alaskan mines, like Red Dog, can be used to make geopolymers that bind their toxic components into a stable material.

**Why not USE tailings from Pebble Mine instead of fighting over how to waste them?**

For making sea wall blocks?
Other Alaskan Materials

Many Alumino-silicates will work

- Kaolin clay
  - from coal mine gangue (material layered in soil above coal deposits)

- Glacial silt / wind-blown loess

- Other clays, zeolites and naturally occurring alumina-silicates

- These will be especially important for producing geopolymer cement in rural Alaskan villages
**Note:**

1) Difference in Ca & Na content in last year’s and this year’s Healy ash samples (HFA & HFABx)

2) Difference in FeO content between raw and calcined Aurora ash (AFA1 & AFAC1)
Alaskan Materials – Particle Size

The red MK is an imported Metakaolin included for reference.

Finer particles provide more reactive surface from which silica & alumina can be dissolved.

Many available materials are suitable.
Feasible and Incrementally Scalable

Large Scale Applications

- Building construction
- Railroad ties
- Roads and bridges
- Retention walls
- Sea walls
- Hazardous waste containment

BP’s North Star artificial island is made using concrete Armor Blocks cast in Fairbanks by University Redi-Mix
Geopolymer Concrete Railroad Ties

ARR Replaces 50,000 Every Year
• Presently imported for $3M annually
• Can be made in Alaska
• Reduced costs (esp. shipping)
• Do not degrade like wood
• Non-polluting
• Creates jobs
• Uses materials that are otherwise disposed of as waste products
• Encourages expansion of Alaska’s rail lines to Canada and over the Yukon
• Used in European and Australian track

A railroad tie aka “sleeper”
Small Applications and Products

Niche Market Applications

- Pre-cast building panels
- Bricks, blocks, pavers, tiles, shingles
- Pipes, culverts
- Refractory applications
- Fireproof insulation and wall panels
- Road and infrastructure repair
- Bridge reinforcement
- Protective coatings
- Adhesives

A cement tub under construction
Small Applications and Products

Countertops and Pre-Casting

- Fairbanks has existing countertop and pre-cast manufacturers
- Fireproof and durable
- Made in Alaska
- Creates jobs in Alaska
- Uses materials that are otherwise wasted
- Reduces importation of similar goods
- Non-polluting

A cast cement sink & counter
New Applications and Products

Insulation and Wall Panels

- Fireproof
- Made in Alaska
- Creates jobs in Alaska
- Uses otherwise wasted materials
- Reduces importation of similar goods
- Non-polluting
- Innovative processes and product designs will be possible that take advantage of geopolymers’ unique performance characteristics.
Valuable over short & long terms

Value Capturing

- Incrementally scalable with investment

- Niche products require little investment
  - Simple, short run pre-cast products
  - Custom products like countertops

- Process and product innovation can be done in Alaska, developing IP for large-scale manufacturing elsewhere

- Meeting infrastructure demands will require greater investment and yield long term value
Transition and impediments will cost?

Internal to the concrete manufacturing & raw material businesses:

- Licensing the use of patented intellectual property
- Batch plant acquisition and adaptation to higher alkalinity materials
- Raw material (e.g. fly ash) quality control & supply contracts
- Mix design development to match performance specifications
- Process control development
- Product development (e.g. certified railroad sleepers)

External – In the concrete product markets:

- Transitioning from prescriptive to performance standard specifications
  - Building components – foundations, walls, beams, etc
  - Transportation infrastructure – pavement, bridges, runways, etc
Usefulness and Problems Solved

Local Geopolymer Production Will
- Provide low-cost, superior quality cement
- Decrease local manufacturing costs
- Create local jobs
- Utilize waste fly ash & mine tailings
- Decrease Alaskan infrastructure costs
- Reduce economic & environmental costs of future development throughout Alaska

Globally Geopolymers Will
- Enable sustainable development
- Decrease rate of CO₂ release
- Conserve fuel
- Improve health and safety
What’s Next in Fairbanks?

Leveraging CCHRC’s expertise and investment
- Expand CCHRC’s 2+GB literature library and publicize it on the web
- Expand collaborations to include more Alaskan businesses

Further economic analysis & business planning
- For local bulk geopolymer concrete production
- For local concrete railroad sleeper production
- For local production of other specific geopolymer products

Product prototyping at CCHRC
- Cement and concrete mix design development and testing
- Radiant floor slabs, countertops, tiles, exterior wall sheathing, roofing shingles, pervious pavement, paving stones, retaining wall blocks, refractory bricks, foamed insulating blocks, railroad ties, etc.

Investigating other available Alaskan materials
“Promoting and advancing the development of healthy, durable, and sustainable shelter for Alaskans and other Circumpolar people.”
Questions?

Contact Cole Sonafrank:

- cole@cchrc.org
- 907 - 457 - 3454
- www.cchrc.org
- P.O. Box 82489, Fairbanks, AK 99708
- 1000 Fairbanks Street, Fairbanks, Alaska
Appendix C

Alaskan Geopolymer Costs

(slide show)
“Promoting and advancing the development of healthy, durable, and sustainable shelter for Alaskans and other Circumpolar people.”
The Cost of Concrete in Fairbanks

What does it cost to produce concrete in Fairbanks?

- What does concrete cost using portland cement?
- What would concrete cost using geopolymer cement?

- The short answers:
  - The costs are about the same for ordinary concrete
  - Geopolymer costs are less for high performance concrete
  - Using portland cement benefits someplace else
  - Using geopolymer cement benefits Fairbanks & Alaska
What is **Concrete**?

- Cement (Binder)
- Sand (Fine Aggregate)
- Rock (Coarse Aggregate)
- Admixtures (Chemicals)
- Water

**Mixing Process**
- Batch Plant (Dry Mixing)
- Mixer / Truck (Wet Mixing)

**Products**
- Concrete
Concrete is **Mostly Aggregate**

- **Concrete**
  - **Batch Plant** (Dry Mixing)
  - **Mixer / Truck** (Wet Mixing)
  - **Cement** (Binder)
  - **Sand** (Fine Aggregate)
  - **Rock** (Coarse Aggregate)
  - **Admixture** (Chemicals)
  - **Water**

**And the aggregate is about the same whatever cement is used**
Concrete is Cement Paste & Aggregate

Concrete = Cement Paste + Aggregate

Cement Paste
- Cement (Binder)
- Admixture (Chemicals)
- Water

Aggregate
- Sand (Fine Aggregate)
- Rock (Coarse Aggregate)
Ordinary Portland Cement (OPC) Paste

- Imported Manufactured Portland Cement
- Imported Admixtures
- Water

Portland Cement Paste
Modern Portland Cement Pastes

- Imported Manufactured Portland Cement
- Imported Supplementary Cementitious Materials *
- Imported Admixtures (Expensive)
- Water

* Higher performance & durability than OPC
* SCM’s include fly ash, metakaolin, silica fume, slag, etc
**Geopolymer**\* Cement Paste

- **Local Alumina Silicate Materials**
  - (Coal Fly Ash, Mine Tailings, Silt, Loess, etc.)

- **Imported Admixtures & Alkali Activator**
  - (Sodium Hydroxide + Sodium Silicate)

- **Water**

---

*aka Alkali-Activated Alumino-silicate Cement*
Concrete Quality ~ Cost

Concrete Specification

Mix Design (How much of what to use):
- Type of Cement
- Types of Supplementary Cementitious Materials
- Type & size gradation of Aggregates
- Types of Admixtures
- Quantity of each component
- Water to cement ratio, slump, etc
- Types, sizes & placement of reinforcement

High Performance & Cost

(Bridges) $$$

Concrete Quality

(Sidewalks) $

Ordinary – Low Cost
Portland Cement Concrete Cost*

Concrete Prescription Specification

Mix Design (How much of what to use):
- Type of Cement
- Types of Supplementary Cementitious Materials
- Type & size gradation of Aggregates
- Types of Admixtures
- Quantity of each component
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- Types, sizes & placement of reinforcement

High Performance & Cost

(Bridges)
Portland Cement Concrete Quality
(Sidewalks)
Ordinary – Low Cost

$200
$84

* Per cubic yard in Fairbanks, Alaska 2010
Geopolymer Cement Concrete Cost*

Concrete Performance Specification

Mix Design (How much of what to use):
- Type of Cement
- Types of Supplementary Cementitious Materials
- Type & size gradation of Aggregates
- Types of Admixtures
- Quantity of each component
- Water to cement ratio, slump, etc
- Types, sizes & placement of reinforcement

High Performance & Cost
- $200 (Bridges)

Geopolymer Cement Concrete Quality
- $84 (Sidewalks)

Ordinary – Low Cost
- $?

* Per cubic yard in Fairbanks, Alaska 2010
### Concrete Material Cost* Breakdown

<table>
<thead>
<tr>
<th>Material</th>
<th>Portland Cement Concrete</th>
<th>Geopolymer Cement Concrete</th>
</tr>
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<tbody>
<tr>
<td>Cement</td>
<td>$47.94 $ / yd³</td>
<td>$0.32 $ / yd³</td>
</tr>
<tr>
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<td>$3.15 $ / yd³</td>
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*Per cubic yard in Fairbanks, Alaska 2010

*Not yet optimized for performance or cost
## Processing Costs* are the same

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* Per cubic yard in Fairbanks, Alaska 2010
Transition and impediments will cost?

Internal to the concrete manufacturing & raw material businesses:

- Licensing use of patented intellectual property
- Batch plant acquisition and adaptation to higher alkalinity materials
- Raw material (e.g. fly ash) quality control & supply contracts
- Mix design development to match performance specifications
- Process control development
- Product development (e.g. certified railroad sleepers)

External – In the concrete product markets:

- Transitioning from prescriptive to performance standard specifications
  - Building components – foundations, walls, beams, etc
  - Transportation infrastructure – pavement, bridges, runways, etc
Feasible and Incrementally Scalable

Large Scale Applications

- Building construction
- Railroad ties
- Roads and bridges
- Retention walls
- Sea walls
- Hazardous waste containment

Bay bridge construction

BP’s North Star artificial island is made using concrete Armor Blocks cast in Fairbanks by University Redi-Mix
Geopolymer Concrete Railroad Ties

The Alaska Railroad Replaces 50,000 Every Year

- Presently imported for $3M annually
- Can & should be made in Alaska
- Reduced costs (especially shipping)
- Do not degrade like wood
- Non-polluting
- Creates Alaskan jobs
- Uses materials that are otherwise wasted
- Encourages expansion of Alaska’s rail lines to Canada and over the Yukon
- Used in European and Australian track
Value Capturing

• Incrementally scalable with investment

• Niche products require little investment
  • Simple, short-run pre-cast products
  • Custom products like countertops

• Process and product innovation can be done in Alaska, developing patentable Intellectual Property for large-scale manufacturing elsewhere

• Meeting infrastructure development demands will require greater investment and yield long term value
Local & Global Benefits

Local Geopolymer Production Will

• Provide low-cost, superior quality concrete
• Decrease costs enabling local manufacturing
• Create local jobs
• Utilize waste fly ash & mine tailings
• Decrease Alaskan infrastructure costs
• Reduce economic & environmental costs of future development throughout Alaska

Globally Geopolymers Will

• Enable sustainable development
• Decrease rate of CO₂ release
• Conserve fuel
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Appendix D

Interior Alaska’s Geopolymer Potential

(document)

Work on fleshing out the economic details involved with Alaskan geopolymer production is on-going and will be incorporated into this document as results evolve. CCHRC will provide the FNSB a copy of the final version. Drafts are available to anyone in the public upon request.
Geopolymer Cement Can — and Should be — Produced in Alaska

A report for and funded by the Fairbanks North Star Borough

By Ty Keltner & Cole Sonafrank, CCHRC

December, 2010

I. Executive Summary
II. Introduction
III. The Business
IV. Products and Services
   • Railroad Ties
   • Bricks, Blocks, Pavers and Tiles
   • Countertops
   • Road Repair
   • Insulation, Wall Panels and Ceiling Tiles
   • Refractory Applications
V. Other Materials
VI. Summary
I. Executive Summary

This document is a preliminary report on the potential of an Alaskan-based cement industry. Our state, like the world, has an increasing need for products made from concrete, which is typically derived from portland cement. However these products can be manufactured in Alaska using local materials rather than portland cement.

Much of the world’s infrastructure is composed of portland cement-based concrete. While an acceptable building material, portland cement has a number of drawbacks: it will crumble and crack in some conditions, performs poorly in salty environments and corrodes the steel used to reinforce it. It also absorbs water and changes shape over time. Perhaps of greatest concern, portland cement produces considerable emissions, uses a substantial amount of energy and infrastructure.

Geopolymer cement is stronger, lighter, more durable, more stable, heat resistant, and impervious to water. Also, the production process is more efficient, less expensive, and less damaging to the environment than portland cement. Geopolymers can be made from fly ash, boiler slag, mine tailings, loess and other ingredients found or produced in Alaska. Using these ingredients will make use of wasted waste product while eliminating the need for portland cement to be manufactured and imported to the state.

Any material made with concrete using portland cement can be produced with concrete using geopolymer cement. Alaskans need a number of products that can be made with geopolymers rather than portland cement. Most notably, Alaska has a railroad industry vital to the state. The Alaska Railroad Corporation (ARR) uses wood ties shipped from the Lower 48. Geopolymer concrete ties are stronger, more durable and less environmentally damaging than traditional wood ties. Geopolymers could be used in another large-scale transportation project —road and bridge construction and repair.

Bricks, blocks, pavers and tiles can all be made from geopolymers. Similarly, concrete countertops are growing in popularity and can also be easily made from geopolymer cement. Other building components include geopolymer insulation, wall panels and ceiling tiles.

Creating geopolymer cement and concrete products would reduce the amount of portland cement shipped to the state, reduce pollution from manufacture of portland cement, use environmentally-hazardous materials that are otherwise disposed of, and create jobs through geopolymer cement manufacturers and the businesses that use their products.

**Geopolymer cement can—and should be—produced in Alaska.**
II. Introduction

Concrete is, and will continue to be, a vital component of the infrastructure upon which our economy is based. About three tons per human on earth are used every year. Concrete is made from locally available sand and gravel bound together by cement. For the last century, that binder has been portland cement, which is made from limestone, alumina-silicate clays, gypsum, and water.

Creating portland cement uses a substantial amount of energy, requires considerable infrastructure and machinery; requires many employees to operate; and produces extensive pollution. The cement kiln is the world’s largest piece of moving industrial equipment and requires enough energy to rotate and fire as high as 3000°F.

Producing one ton of portland cement releases approximately one ton of carbon dioxide into the atmosphere and consumes the energy equivalent of 450 pounds of coal. The cement industry contributes 5-8% of global carbon dioxide emissions, though recent estimates place that number even higher. Cement companies have begun retrofitting plants to reuse the waste heat from manufacturing process. However, even these plants produce substantial emissions.
In addition, another 1% of U.S. energy consumption goes into producing gypsum-based drywall releasing another 25 billion pounds of CO₂ annually.

In 2006, approximately 100 million tons of portland cement was produced in the United States and more than one billion tons in China. The total 2006 worldwide production was about 2.5 billion tons. Annual demand continues to increase.

Portland cement also suffers from a range of structural concerns. It does not hold up well in salty environments and the steel used to reinforce it tends to slowly corrode away. Portland cement also absorbs water and expands and contracts significantly with temperature changes.

All of the concrete in Alaska is made using portland cement imported from outside the state. The cost of importing cement inhibits Alaska’s infrastructure development, economic stability and prosperity. Enabling local production of cement could fundamentally alter the economic viability of rural Alaskan villages as well as large-scale transportation projects.

**Geopolymer Cements**

New cements have been developed that are substantially superior to portland cement in all performance measurements. Geopolymers and magnesium phosphate cements are strong, fireproof, waterproof, and are already commercially available elsewhere in the world. They bond strongly to most materials, do not expand or contract, are foamable, and are resistant to salts, acids, and alkalis. They also require less energy to make and are more environmentally benign. In contrast to portland cement, creating one ton of geopolymer cement creates only .1-.15 tons of CO₂. Thus, 7-9 times as much geopolymer cement can be produced for the same level of CO₂ emission.

Geopolymers cure more rapidly than portland-based cements. They gain most of their strength within 24 hours. However, they set slowly enough that they can be mixed at a batch plant and delivered in a concrete mixer. Geopolymers also have the ability to form a strong chemical bond with previously placed material and expand relatively little.

Creating cement requires an alumina silicate material, an alkali activator such as sodium hydroxide, sodium silicate and water.
Nearly any product made with concrete can be made with geopolymer cement. The applications include buildings, transportation, and many other areas. Alaska has an urgent and growing need for many of the concrete products currently made using portland cement. The state is one of the best-suited locations to utilize geopolymer cement and concretes due to their increased strength, durability, and use of Alaskan ingredients. Geopolymers can be made in-state from a number of materials found in Alaska, many of which are typically considered waste.

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Source</th>
<th>Alaskan Source</th>
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</thead>
<tbody>
<tr>
<td>Coal fly ash</td>
<td>Coal power plants</td>
<td>Red Dog Mine, Kensington Mine, upcoming Pebble Mine</td>
</tr>
<tr>
<td>Mine tailings</td>
<td>Mines with complex ore bodies</td>
<td>Lakes, rivers</td>
</tr>
<tr>
<td>Silt</td>
<td>Bodies of water</td>
<td></td>
</tr>
<tr>
<td>Loess</td>
<td>Wind-blown silt, soil with no organics</td>
<td></td>
</tr>
<tr>
<td>Metakaolin</td>
<td>Kaolin clay</td>
<td>Usibelli Mine</td>
</tr>
<tr>
<td>Blast furnace slag</td>
<td>Metal smelting plants</td>
<td>none</td>
</tr>
<tr>
<td>Other alumina silicates</td>
<td>zeolite deposits</td>
<td></td>
</tr>
</tbody>
</table>

Commonly used materials include metakaolin (calcined kaolin) found surrounding coal deposits, fly ash and other by-products of high temperature industrial processes, e.g., blast furnace slag, and zeolite, which is commonly found in Alaska.
The dry alumina-silicate powder is combined with a strong alkali solution to form the cement binder paste. A combination of sodium hydroxide (lye), sodium silicate (water glass) and clean water is typical. Until it cures, the cement is highly caustic (even more than portland cement), so additional care must be taken to handle it safely. Clean sands, fillers, aggregates and reinforcing materials can also be included. Many such mixes require additional heat, but some do cure to full strength at room temperatures. The alkali activators needed for geopolymers, such as sodium hydroxide and sodium silicate, must be shipped to Alaska. They are inexpensive and readily available in dry form.

Cold Climate Housing Research Center has invested substantial resources over the past two years in researching and experimenting with modern cements and investigating how they can be made using raw materials readily available in Alaska, including ash from coal-fired electrical generation plants and mine tailings. The performance characteristics of these cements make them well-suited for creating high performance products that could resolve many existing problems with housing in cold climates while reducing environmental impacts.

With so much potential for alternative cement products, businesses can be established in the untapped Alaskan market. These businesses will utilize otherwise wasted materials, grow the state economy, reduce pollution and provide jobs.
III. The Business

Geopolymer businesses have evolved around the world with Australia being the leader in geopolymer commercialization. Midscale geopolymer businesses began to sprout in 2008 when Zeobond began using fly ash and boiler slag to create geopolymers.

The material can be used for a wide variety of applications, including low CO$_2$ cements, radioactive and toxic waste encapsulation, foam for high temperature insulation, aluminum foundry equipments, sealants, tooling for aeronautics, fire resistant/heat resistant carbon-fiber composites and much more. The dry powders are mixed with liquids comprised mostly of water and placed by pouring, spraying and/or troweling into or onto their intended form and allowed to cure. The cement binder may also be mixed with a full range of sands, fillers, aggregates and reinforcing materials to form stuccos, mortars and concretes. However not all of these uses are appropriate for an Alaskan business application.

Portland cement is used to create concrete, which, in turn, is used to create a variety of products. Geopolymer cement can be substituted for portland cement in any of those products.

The end products will reap the strength, durability and other benefits of geopolymers.
Creating geopolymer cement is substantially less expensive, less expansive, less polluting, and less involved than creating portland cement. Making a large quantity of geopolymers would require a plant roughly the size of a portland cement batch plant. The large kiln and other infrastructure needed to make portland cement are not needed for geopolymer production, nor does it require the tremendous amount of energy that portland cement consumes. Manufacturing geopolymers produces little or no pollution. The following is the infrastructure needed for manufacturing of portland cement vs. manufacturing geopolymer cements.

**Process for creating portland cement:**

![Portland Cement Process Diagram](image)

**Process for creating geopolymer cement using rock or other unprocessed material:**

![Geopolymer Cement Process Diagram](image)

**Process for creating geopolymer cement using fly ash:**

![Geopolymer Cement Process Diagram](image)
IV. Products and Services

The following is an analysis of the variety of products that can be made in Alaska, using cements created from Alaskan materials and concrete created using these Alaskan cements.

Railroad ties

Railroad ties, also called “sleepers”, are used around the world to secure the track in place. Wooden ties, most commonly used, consume wood stock that can be used for other purposes, and are coated with creosote, which is known to be environmentally damaging. In terms of durability, wooden ties split, rot and suffer from insect damage.

The ARR uses hardwood ties on nearly all its track and uses concrete ties on high degree turns. The ties are shipped to Anchorage from southern Indiana.

The Alaska Railroad is composed of 651 miles of track. There are approximately 3,000-3,250 railroad ties per mile. For the purposes of simplicity, the calculations below use 600 miles of track, and 3,000 ties per mile.

**Railroad figures**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Tie dimensions</td>
<td>7 in. x 9in. x 8.5 ft.</td>
</tr>
<tr>
<td>Miles of track</td>
<td>600</td>
</tr>
<tr>
<td>Number of ties per mile</td>
<td>3,000</td>
</tr>
<tr>
<td>Total ties in Alaska</td>
<td>1,800,000</td>
</tr>
<tr>
<td>Expected lifetime of a tie (in years)</td>
<td>30-40</td>
</tr>
<tr>
<td>Number of ties changed out per year</td>
<td>50,000</td>
</tr>
<tr>
<td>Cost of a hardwood tie</td>
<td>$65</td>
</tr>
<tr>
<td>Cost of a concrete tie</td>
<td>$110</td>
</tr>
<tr>
<td>Dollars spent on hardwood ties per year</td>
<td>$3,250,000</td>
</tr>
</tbody>
</table>

Concrete ties do not split, or suffer insect infestation. Concrete ties also fare better in Alaska’s harsh climate. The properties of concrete ties provide substantial benefit over wooden ties, but concrete created with geopolymers provides and even greater benefit. Geopolymer concrete ties will not deteriorate as quickly as those made with portland cement.
Geopolymer concrete ties have been used in Russia, among other places, where they were found to be in good working order after 13 years of service.

**Concrete railroad tie figures**
- Concrete per tie (cubic yards) .14
- Concrete needed per mile (cubic yards) 430
- Tons of cement needed per mile 120
- Tons of sand and gravel needed per mile 7,600

As an abbreviated calculation, the distance from Fairbanks to Whitehorse is about 600 miles. By railroad, that distance would require two million ties. Constructing the ties from concrete would require 270,000 cubic yards of concrete which would use 76,000 tons of cement and 500,000 tons of sand & gravel. All of the cement can be made in-state, thus avoiding the cost of importing wooden ties.

Any Alaska-produced railway ties would have to meet industry standards before they can be used. The Alaska Railroad Corporation will only use ties that meet the American Railway Engineering and Maintenance-of-Way Association (AREMA) requirements. The Transportation Technology Center Inc. (TTCI), located in Colorado, tests materials and other rail components for strength, durability and other characteristics.

**Bricks, blocks, pavers, tiles**

Bricks, pavers and blocks made with geopolymers are more durable than those made with Portland cement products. Outside the United States, geopolymer blocks have been used to construct residential houses, garages, and fences.

Currently there are many companies in Alaska that make bricks, tiles, pavers, and other block materials. They use portland cement with a variety of aggregates. So introducing a successful new block business based on Alaskan geopolymer-made products would be entering a market that already has competitors. One option to avoid competition is to start a geopolymer business that makes a line of products that includes bricks, blocks and pavers. The blocks can be sold to local companies as well as large chain stores across the state. A diverse concrete business should include a variety of concrete block products. This business will create jobs while making an Alaska product.

**Road/Bridge/Dam Construction**

Today, roads, bridges, dams and other infrastructure are commonly composed of concrete created with portland cement. Fly ash is often mixed in with portland cement to improve the end product’s strength, heat resistance, durability, moisture permeability, curing and shrinkage. Fly ash inclusion in portland cement products is increasing across the United
States and is supported by the Environmental Protection Agency. Many states have laws, regulations, or policies governing the use of fly ash in road construction.

![Top Uses of Coal Fly Ash, 2003](image)

**Source: American Coal Ash Association 2004**

Just as fly ash by itself can be used as a binder, mine tailings, loess, slag and other materials can also be used exclusively, or in combination with portland cement.

Alaska’s roads and infrastructure suffers extensive weathering damage due to the state’s varying climate. In addition, Alaska has tremendous need for future roads, bridges and other infrastructure. Portland cement concretes could probably be improved by combining fly ash from Alaska’s power plants or mine tailings from the state’s many mining operations. Better yet, simply using fly ash to create geopolymer cement for concrete will make that infrastructure far more durable and less prone to deterioration in Alaska’s harsh climate.

**Pipes**

The benefit of concrete pipe has been evident for many years. Concrete reinforcing adds strength, durability and reliability to pipe for many functions. Making concrete with
geopolymer cement increases those benefits with the significant advantage of being environmentally friendly. Geopolymer cement makes particularly good sewer pipe due to its higher resistance to corrosion from acids.

**Fireproof insulation and wall panels**
Creating fireproof coating is not a difficult process. Typically a geopolymer substance is layered onto another substance via rolling, spray or other application. Often fabrics are incorporated into geopolymer layers.

**Countertops**
Concrete countertops are gaining popularity. Several different types of cement are commonly used. Because geopolymer cements are more heat resistant, less permeable and harder they should make better countertop than portland cement.

**Refractory applications**
Due to the inherent fireproof and heat resistant characteristics of geopolymers, they are ideal for use as heating system parts, firebrick, fireplace mortar, metal forms/molds and in many other applications.

**V. Other Materials**
Another alternative type of cement is magnesium phosphate cement (MPC). Magnesium phosphates can be made from many materials also found in Alaska. However, MPCs are only appropriate for niche market applications. The cost of producing magnesium phosphate cement is higher and may generally be uneconomical. However, there are a number of characteristics of magnesium phosphates that may outweigh the higher expense, such as magnesium phosphates’ extremely fast set time and fire retardant properties.

**VI. Summary**
Our civilization was built with portland cement. While having many benefits, the environmental consequences of making portland cement are substantial, including increased production of CO\(_2\). In addition, portland cement changes shape and deteriorates over time, depending on the conditions in which it is used.

Geopolymers are stronger, lighter, more durable, more stable and impervious to water. In addition, their production is more efficient than portland cement. They cure much more rapidly than portland cements and form a strong chemical bond with previously placed material.

Creating one ton of geopolymer cement creates only .1-.15 tons of CO\(_2\). Thus, seven to nine times as much geopolymer cement can be produced for the same level of CO\(_2\) emission.
Less machinery and energy is need to create geopolymer cement. The ingredients for geopolymers are available in Alaska, including fly ash, mine tailings, glacial silt, loess and others. Some of these materials, specifically fly ash and mine tailings, are hazardous to the environment. Thus, using them to create a value-added product would remove them from the waste stream and the environment.

A geopolymer industry would provide a number of economic benefits, including jobs for Alaskans, promotion of Alaskan-made products, and costs saved through waste reduction and mitigation.

Any product made with portland cement and portland cement-based concrete can be made with geopolymer cement. The applications are endless for transportation, infrastructure, refractory applications and much more. Alaska has a specific need for railroad ties. Geopolymer ties will last longer, are more resilient and can be made from materials currently going to waste. Roads, bridges and other infrastructure can also be constructed or repaired using geopolymer concretes. Geopolymer cements are also ideal for building applications including bricks and pavers, wall panels, countertops and pipes.

Economically competitive high performance cement can, and should, be produced in Alaska using Alaskan resources, creating permanent jobs and diversifying Alaska’s economy.
This draft is a work in progress
Appendix E

A comparison of portland and geopolymer cement costs

(figure)
## Preliminary Gross Concrete Cost Estimates

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>$ / ton of material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement (min)</td>
<td>$170</td>
</tr>
<tr>
<td>Portland Cement (max)</td>
<td>$300</td>
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<td>Admixtures (min)</td>
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<td>Admixtures (max)</td>
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<td>Sand (min)</td>
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<tr>
<td>Sand (max)</td>
<td>$9</td>
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<tr>
<td>Rock (min)</td>
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<td>Rock (max)</td>
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<td>$3</td>
</tr>
<tr>
<td>Aurora Bottom Ash (min)</td>
<td>$0</td>
</tr>
<tr>
<td>Aurora Bottom Ash (max)</td>
<td>$3</td>
</tr>
<tr>
<td>Healy Fly Ash (min)</td>
<td>$5</td>
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<tr>
<td>Healy Fly Ash (max)</td>
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<td>Other (min)</td>
<td>$5</td>
</tr>
<tr>
<td>Other (max)</td>
<td>$8</td>
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<tr>
<td>Freight (Seattle-&gt;Fairbanks)</td>
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<td>Industrial Bulk Price (min)</td>
<td>50%</td>
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<tr>
<td>Sodium Hydroxide (min)</td>
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<td>Sodium Hydroxide (max)</td>
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</tr>
<tr>
<td>Sodium Silicate (min)</td>
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<td>Sodium Silicate (max)</td>
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<tr>
<td>Potassium Hydroxide (min)</td>
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<tr>
<td>Other Additives (min)</td>
<td>$1,800</td>
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<tr>
<td>Other Additives (max)</td>
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</table>

### Portland Cement-based Concrete

<table>
<thead>
<tr>
<th>ton / cu yd of concrete</th>
<th>$ / cu yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.12</td>
<td>$84</td>
</tr>
<tr>
<td>2.12</td>
<td>$196</td>
</tr>
<tr>
<td>Portland Cement (min)</td>
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<tr>
<td>Water (min)</td>
<td>$0.11</td>
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<tr>
<td>Water (max)</td>
<td>$1.12</td>
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### Not Yet Optimized Geopolymer-based Concrete

<table>
<thead>
<tr>
<th>ton / cu yd of concrete</th>
<th>$ / cu yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.27</td>
<td>$84</td>
</tr>
<tr>
<td>2.27</td>
<td>$224</td>
</tr>
<tr>
<td>Aurora Fly Ash (min)</td>
<td>$0.00</td>
</tr>
<tr>
<td>Aurora Fly Ash (max)</td>
<td>$0.55</td>
</tr>
<tr>
<td>Healy Fly Ash (min)</td>
<td>$0.32</td>
</tr>
<tr>
<td>Healy Fly Ash (max)</td>
<td>$0.53</td>
</tr>
<tr>
<td>Other (min)</td>
<td>$0.00</td>
</tr>
<tr>
<td>Other (max)</td>
<td>$0.21</td>
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<td>Sand (max)</td>
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<td>Sodium Silicate (min)</td>
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<td>Sodium Silicate (max)</td>
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<tr>
<td>Other Additives (min)</td>
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<tr>
<td>Water (min)</td>
<td>$0.12</td>
</tr>
<tr>
<td>Water (max)</td>
<td>$1.18</td>
</tr>
</tbody>
</table>

* Note:
1. The "min" and "max" here do not mean minimum and maximum possible costs. They estimate the minimum and maximum costs of the specified range of mix designs when produced on an industrial scale. Commercially optimal mix designs may fall outside of this range.
2. This simple first comparison does not take into account the differences in cement quality, nor what those differences mean to quantity required for any given use/project. Given that the base performance of geopolymers is superior to portland cement, less should be required (in relation to aggregate) to achieve comparable performance concrete.
3. The minimum portland cement costs have been reviewed and corrected by a local Redi-mix producer. The Geopolymer material costs are guesses based upon bulk retail costs rather than industrial scale quotations.
4. The geopolymer mix designs themselves have not been optimized for any specified level of product performance. They are meant to reflect a likely worst case for cement somewhere in the middle of the potential performance range.
Appendix F

Alumina-silicate material sample identification key

Elemental Composition of Alaskan Raw Materials
(figures)

Particle Size Distribution Analysis Results
(figures)
# Alumina-silicate material sample identification key

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MK</td>
<td>PowerPozz, Commercial Metakaolin for reference</td>
</tr>
<tr>
<td>AFA1</td>
<td>Aurora Energy’s Chena power plant fly ash, sample 1</td>
</tr>
<tr>
<td>AFAC1</td>
<td>Aurora Energy fly ash, sample 1, calcined at 1400°F for 30 minutes</td>
</tr>
<tr>
<td>HFA</td>
<td>Healy 1 power plant fly ash, 2009 sample (still using lime to remove sulphur)</td>
</tr>
<tr>
<td>HFAB1</td>
<td>Healy 1 fly ash from bin 1</td>
</tr>
<tr>
<td>HFAB3</td>
<td>Healy 1 fly ash from bin 3</td>
</tr>
<tr>
<td>HFAB6</td>
<td>Healy 1 fly ash from bin 6</td>
</tr>
<tr>
<td>UAFFA</td>
<td>UAF power plant fly ash</td>
</tr>
<tr>
<td>FK2</td>
<td>Fort Knox gold mine tailings, sample 2, finest near the dam</td>
</tr>
<tr>
<td>POGO</td>
<td>Pogo gold mine tailings</td>
</tr>
<tr>
<td>RedDog</td>
<td>Red Dog lead/Zinc mine tailings - Toxic</td>
</tr>
<tr>
<td>RCL</td>
<td>Loess from a cut bank along Rossie Creek road</td>
</tr>
<tr>
<td>ELS</td>
<td>Eli Sonafrank’s lot loess/silt, near the top of Ester Lump</td>
</tr>
<tr>
<td>CRM</td>
<td>Chena River Mud, from 50’ from the river @ Chena Pump wayside</td>
</tr>
<tr>
<td>DS-HC</td>
<td>David Stannard’s sample of Healy Clay</td>
</tr>
<tr>
<td>DS-HG</td>
<td>David Stannard’s sample of clay from Hinkley Gulch</td>
</tr>
<tr>
<td>DS-L</td>
<td>David Stannard’s sample of clay from the Livengood highway</td>
</tr>
<tr>
<td>DS-MD</td>
<td>David Stannard’s sample of clay from Murphy Dome</td>
</tr>
<tr>
<td>DS-SF</td>
<td>David Stannard’s sample of clay from UAF’s Silver Fox deposit</td>
</tr>
<tr>
<td>DS-TH</td>
<td>David Stannard’s sample of clay from the Taylor Highway</td>
</tr>
</tbody>
</table>
Appendix G

Usibelli Coal Produces More Than Power, Pollution and Profit

(op-ed)
Usibelli Coal Produces More Than Power, Pollution and Profit

by GH Cole Sonafrank, November 21, 2010

Burning Usibelli coal does not simply produce power, pollution and profit. Burning coal also produces cement and a lightweight aggregate. It could play a valuable role in Alaska’s transition to a sustainable economy. We should stop calling the cement and aggregate “waste” and throwing it away, or worse treating it like pollution. This would allow us to stop importing all the portland cement we use in Alaska from places like Korea.

Alaska’s resources are underutilized. Alaska’s development requires affordable concrete. Alaska’s environmental extremes require technological adaptation and high construction standards. Alaska’s economy needs diversification. Alaskans need jobs. Alaskans are at the forefront of researching and developing technologies for sustainable living in the Arctic. People all over the world are waking up to the fact that a key requirement for achieving sustainability is not wasting resources. How far behind developing countries will we let Alaska get before we too wake up and recognize our blessings for what they are and work to do our best with them?

The production of cement, as it is usually done, takes a lot of energy and generates a lot of air pollution. To produce one ton of portland cement requires the energy equivalent of about 450 pounds of coal and releases about one ton of carbon dioxide into the atmosphere. The vast majority of the 2.8 billion tons of portland cement used annually around the world is produced by burning fossil fuels, all too often combined with whatever else will burn like tires or medical wastes, and is a major contributor to air pollution.

In the United States and most of the developed nations, we have learned that allowing fine particulate matter, let alone toxins, to fly up and out of smoke stacks into the air people breathe leads to expensive, preventable health and environmental problems. So, at least in the USA, cement and power plant emissions are regulated – which helps the price of cement and electricity produced domestically to cover more of their long-term costs. Imported cement thus appears to be relatively cheap (ignoring unregulated foreign costs). This, combined with the potential impact on our struggling economy, is one of the rationales for retaining loop holes in, and not tightening, air quality regulations.

Alaska’s blessing

Alaska is blessed to have tremendous deposits of coal that is very different from that in the rest of the United States. We appreciate only part of this blessing – the low sulfur content and near absence of toxic metals like mercury and arsenic commonly in other types of coal. Blinded by outmoded preconceptions, we are mistaken if we think that the rest of the blessing is a curse: Usibelli coal contains an abnormally high amount of calcium.

When the coal is burned to produce heat (to produce steam, to spin turbines, to generate electricity), the calcium ends up in the ash along with a lot of silicon and aluminum, a bit of iron,
magnesium, sodium and unburned carbon and traces of other metals. Depending upon how the power plants are operated, that ash is produced in two forms. We should be calling one “cement” and the other “aggregate.” Presently we call them “fly ash” and “bottom ash” and pay to waste them both.

Portland cement hardens into a useful material because the calcium, silicon and iron that are its main components have been heated up to drive off the carbon dioxide and water and make them more chemically reactive. Fly ash, as a combustion product, has been made similarly reactive. It is comprised mostly of extremely fine particles of silicon, aluminum and calcium oxides in an amorphous, glassy form that is more reactive than the crystalline forms typical in nature.

For decades concrete producers have added fine reactive particulates to portland cement mixes to improve the characteristics of concrete, which is cement plus sand and rock. Usually the goals are to decrease concrete costs and/or increase its strength and durability. Three of these materials are silica fume (an industrial by-product), metakaolin (calcined kaolin clay) and fly ash from coal-fired power plants. Standards have slowly evolved to allow the addition of these materials. They are required for making the highest strength concretes. Ironically, this is the root of why the high calcium content of Alaskan fly ash has not been appreciated as advantageous.

**Prescriptive vs. Performance Standards**

Concrete is a crucial component of our civilization. About three tons per person on earth are used each year. While concrete cracking may be inevitable, concrete crumbling causes catastrophes. Consequently, we have chosen to control its use by setting standards. Our standards do not simply specify how the concrete product must perform – that is usually difficult to verify while a bridge or skyscraper is being built. For a variety of reasons, including the complexity of cement chemistry, most of our standards specify exactly what concrete must be made of and how it must be used. So, what is and is not acceptable for use in concrete has been carefully, clearly and simply defined. Before the advent of pocket computers, such simplicity was helpful.

Establishment of such definitions and standards is not a scientific process, and the outcomes directly affect the economies and opportunities of individuals, businesses, regions and nations. This is what politics is all about. As in so many other things, Alaska’s needs for concrete are different from the rest of the United States. Our geographical differences, including extreme environmental conditions the high risk of severe earthquakes, the exorbitant costs of transportation across our vast wilderness, and the lack of infrastructure development and local availability of resources like fly ash, are not always reflected in the standards which control our construction industries. The rational, efficient, sustainable and profitable development of Alaska is stymied by the unsuitability of many standards. That is not to say that Alaska would
be better off with fewer standards. Rather, we along with our children’s great-great grandchildren need standards appropriate to Alaska.

Fortunately, some problems with national standards are not so much a matter of this is right and that is wrong. They are more that this detail or approach is obviously a problem for Alaska and while it may be politically practical for other states now, before long it will be a problem for them too. Our proactive efforts to improve standards so that they fit the needs of Alaska may also be in the national interest.

So what does this have to do with fly ash and cement? Specifications for portland cement-based concrete mixes require fly ash that falls within the American Society for Testing and Materials (ASTM) definitions of “Class F” or “Class C” fly ash. Most of the fly ash in the USA is of the low calcium Class F variety. Some meets the definition of the higher calcium Class C fly ash. Using Class F is a simple matter of following established guidelines. The narrowness of the Class F definition ensures that the performance of the concrete will remain within predetermined parameters. Since its definition is much broader, using Class C fly ash is more complicated. Project specifications rarely include a method for accepting an appropriate concrete mix using Class C fly ash. Mix design standards based upon the actual content and characteristics of the particular fly ash available, even if it has been demonstrated to produce superior performance concrete, are not readily available. Such standards would open up the possibility for making superior concretes using less than the amounts of portland cement presently required. This tactic provided some industry protection back when cement made in the USA was competitive on the global market.

American concrete standards, specifying prescriptions for how concrete must be made rather than how it must perform, are increasing construction costs and inhibiting innovations in concrete technology. All around the world technological innovations are rapidly improving concrete’s durability, energy efficiency and environmental sustainability. The ongoing evolution of concrete depends primarily upon improving the cement that binds it all together. Fundamentally improving that cement requires remembering that the calcium-silicate-hydrates (CSH) formed from portland cement are but one of many molecular structures that can effectively bind aggregates into concrete. Many other types of cement have long been used for applications that require their particular performance properties and justify their typically higher costs.

**Portland & Geopolymer Concretes**

Amorphous poly(sialate-siloxo) structures are becoming increasingly important in concrete development; perhaps not only the evolution of concrete technology, but of concrete as it ages. Unlike calcium-silicate-hydrates, these are polymeric molecular structures of silicon, oxygen and aluminum formed around, and charged balanced by, sodium, potassium and/or calcium cations. They are created by the condensation of silicates and aluminates that have been dissolved in an alkaline solution.
Thus, global interest in them is converging from different fronts. The first is striving to understand and perhaps resolve the most pernicious problem causing the premature degradation of our concrete infrastructure: the Alkali Aggregate Reaction (AAR). The second is producing inorganic polymer cements, also known as alkali-activated alumino-silicates or geopolymers, taking advantage of their low cost, superior performance, and small environmental impact.

The Alkali Aggregate Reaction stems from fundamental properties of portland cement: its structure depends upon the inclusion of water, it is permeable to water and it is alkaline. Some of the water along with some of the calcium ever-so-slowly dissolves silica and alumina from the surface of the sand and rock in concrete. These condense into molecules that are larger than the space they had previously occupied, weakening or breaking the calcium-silicate-hydrate structure surrounding them. Eventually the concrete crumbles.

In contrast, geopolymer cement is not based upon water and is much less permeable. Its rapid formation requires the dissolution and condensation of silica and alumina from source material that is far more reactive than the sand and rock aggregate. Research and evidence from concrete made in Russia in the 1950s using alkali-activated blast furnace slag indicates that it is more durable than portland cement concrete. The supposition is that eventual products of the Alkali Aggregate Reaction are readily incorporated into the similar surrounding structure.

**Modern Hybrid Cements**

One of the reasons usually given for including supplemental cementitious materials (SCM) like silica fume, metakaolin, ground slag, or fly ash into modern cement mixes is to improve its resistance to the Alkali Aggregate Reaction. Another method being investigated is the addition of an alkali activator to the mix. That is, one of the main paths of current concrete evolution is toward using cements which are hybrids of calcium-silicate-hydrates and amorphous poly(sialate-siloxo) structures.

And that leads back to why the ash produced from burning Usibelli coal is a cement we should stop wasting. It is a fine, reactive, high-calcium alumino-silicate resource that is ready to use without requiring expensive processing or transportation across the Pacific Ocean. Can it be used to replace portland cement today? No. Can it become a core commodity in Alaska’s future? Yes. Will that happen automatically? No. Should we proactively help ensure that it does?