Abstract — The production of cement is increasing about 3% annually. As the production of one ton of cement liberates about one ton of CO$_2$ to the atmosphere, currently the contribution of Portland cement production worldwide to the greenhouse gas emission is about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth’s atmosphere. Aside from that, cement is among the most energy-intensive construction materials as well. Due to the environmental concern, the production of ordinary Portland cement attracts critics.

The concrete industry has recognized these issues. For example, the U.S. Concrete Industry has developed plans to address these issues in ‘Vision 2030: A Vision for the U.S. Concrete Industry’. In this document, strategies to retain concrete as a construction material of choice for infrastructure development, and at the same time to make it an environmentally friendly material for the future have been outlined.

One strategy to make concrete ‘greener’ construction material is to utilize fly ash, either as partial or total substitute for Portland cement in concrete. This attempt results in twofold benefits, i.e. to provide a solution with regard to the concern on the carbon dioxide emission from Portland cement production, and to provide way to effectively use fly ash. Fly ash, the by-product material from burning coal especially in power stations, is available abundantly worldwide. Its availability is increasing and yet its utilization to date is still very low. Without proper plan, the management of fly ash may incur cost, and potentially harm the natural environment as well. This paper discusses the technology and the current progress of research on utilizing fly ash in concrete.

Keywords: Cement, Concrete, Fly Ash, Environmental Concern

I. INTRODUCTION

Portland cement is one of the most popular and major construction materials worldwide. In the foreseeable future, this tendency will remain so. The cement production is expected to rise from 1.7 billion tones in 2000 to 2 billion tones in 2010, whereby the major increase will take place in China and India [1].

However, Portland cement production raises environmental concern, not only due to highly energy intensive, but also due to high amount of carbon dioxide released to the atmosphere. Production of one ton Portland cement will release one ton of carbon dioxide into atmosphere. Moreover, there is also concern on the durability of the concrete structures, especially those built in aggressive environment [2].

On the other hand, fly ash, “the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system” [3], is available abundantly worldwide. In 2001, the fly ash production in the USA was in the order of 68 million tons, but only 32 percent was used in various applications, such as in concrete, structural fills, waste stabilisation/solidification, etc. [4]. Worldwide, the estimated production of coal ash in 1998 was more than 390 million tons. The main contributors for this amount were China and India. Only about 14 percent of this fly ash was utilized, while the rest was just disposed in landfills [5]. By the year 2010, the amount of fly ash produced worldwide is estimated to be about 780 million tons annually [6].

The utilization of fly ash and other by-product materials, such as granulated blast furnace slag, rice husk ash, as a substitute or partially substitute of Portland cement in concrete has been studied intensively and extensively. Partial substitution of Portland cement by 20-30% fly ash has become a common practice. A more substantial development in this area were the development of high volume fly ash concrete with 50-60% Portland cement replacement by using fly ash, and the development of fly ash-based geopolymer concrete whereby the use of Portland cement is totally replaced by the geopolymer matrix using fly ash as the source material.

This paper discusses the strategy to utilise fly ash in order to make concrete more environmentally friendly construction material for a sustainable development.

II. PORTLAND CEMENT: PRODUCTION AND ENVIRONMENTAL ISSUE

Table 1 shows the Portland cement production till the year of 2010 in million tonnes. By releasing one ton of carbon dioxide for every ton of Portland cement produced, the
Portland cement industry contributes around 7% of the total amount of carbon dioxide worldwide [5]. Significant improvement in the technology to produce Portland cement to make it more environmentally friendly is not expected in the near future. The production of one ton Portland cement also requires approximately 4 GJ energy, to put it into one of the most energy intensive construction materials [7].

| TABLE 1: REGIONAL AND WORLD CEMENT PRODUCTION TO YEAR 2010 (IN MILLION TONNES) [5] |
|---------------------------------|------|------|------|-------|----------------|----------------|
|                                 | 1995 | 2000 | 2005 | 2010  | % of total 1995 | % of total 2010 |
| European Union                  | 168.1| 187.9| 194.1| 189.3 | 12.1            | 9.7             |
| Other Europe                    | 65.8 | 80.0 | 90.2 | 94.7  | 4.7             | 4.9             |
| Former Soviet Union             | 58.1 | 80.3 | 110.1| 128.2 | 4.2             | 6.6             |
| North America                   | 92.9 | 94.9 | 94.8 | 94.7  | 6.6             | 4.9             |
| C/S America                     | 89.4 | 106.6| 127.4| 145.0 | 6.4             | 7.5             |
| Africa                          | 64.8 | 74.3 | 80.7 | 85.5  | 4.6             | 4.4             |
| Middle East                     | 63.5 | 75.6 | 76.9 | 73.4  | 4.6             | 3.8             |
| East Asia                       | 623.4| 732.7| 798.8| 844.3 | 44.6            | 43.4            |
| S/SE Asia                       | 161.2| 219.1| 255.0| 279.2 | 11.6            | 14.4            |
| Oceania                         | 8.0  | 10.6 | 11.1 | 11.8  | 0.6             | 0.6             |
| World totals                    | 1396.1| 1662.1| 1839.1| 1946.1| 100.0           | 100.0           |

The need for reducing the environmental impact of concrete has been recognized by the concrete industries. The document entitled “Vision 2030: A vision for the US Concrete Industry” states that ‘concrete technologist are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice. Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gas’ [7, 8].

In order to produce environmentally friendly concrete, Mehta [9] suggested the use of fewer natural resources, less energy, and minimise carbon dioxide emissions. He categorized these short-term efforts as ‘industrial ecology’. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption. Likewise, McCaffrey [10] suggested three alternatives to reduce the amount of carbon dioxide (CO₂) emissions by the cement industries, i.e. to decrease the amount of calcined material in cement, to decrease the amount of cement in concrete, and to decrease the number of buildings using cement.

In this view, the most feasible alternative to reduce the environmental impact of concrete is to reduce the amount of Portland cement used.

III. FLY ASH: AVAILABILITY, PROBLEM AND POTENTIAL

Table 2 shows estimation on the fly ash production in 2000, with the total production worldwide estimated to be 600 million tonnes worldwide, with China, USA and India as the biggest producers. This yearly production should be added with the amount of fly ash that has been stockpiled over the years. In the near future, it is expected that the production of fly ash is steadily increasing, as the power produced by burning coal is remain the cheaper alternative, and as the high quality coal is available abundantly worldwide [1]. So far, only about 14 percent of this fly ash was utilized, while the rest was just disposed in landfills [5]. Without proper attention, disposing fly ash in landfills may cause another threat to the environment.

The most commonly available fly ash is low calcium or class F fly ash with less than 20% of calcium oxide, which in itself possesses little or even does not posses any cementitious properties. However, with the presence of moisture at ordinary temperature, it will chemically react with calcium hydroxide to form compound having cementitious properties, thus plays a role as an artificial pozzolan. The main constituents of fly ash are silicon and aluminium oxides [3].

In this regard, the incorporation of 20-30% of fly ash to partially replace the use of Portland cement in concrete has become a common practice in construction work.
Other noted advancement in the technology to utilize fly ash in concrete was the development of High Volume Fly Ash (HVFA) concrete and fly ash-based Geopolymer concrete. In HVFA, 50 to 60% of fly ash is to be used to replace the use of Portland cement in concrete, while for geopolymer concrete it does not require any Portland cement, as its is totally replaced by geopolymer paste with fly ash as the source material.

The use of fly ash in concrete is therefore resulting twofold environmentally benefit, i.e. reduce the use of Portland cement and utilize by-product material.

<table>
<thead>
<tr>
<th>Country</th>
<th>Production</th>
<th>Utilization in concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>&gt;200</td>
<td>&gt;15</td>
</tr>
<tr>
<td>India</td>
<td>&gt;80</td>
<td>5%</td>
</tr>
<tr>
<td>USA</td>
<td>&gt;60</td>
<td>10%</td>
</tr>
<tr>
<td>Russia</td>
<td>60</td>
<td>5</td>
</tr>
<tr>
<td>Germany</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>UK</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

**TABLE 2: ESTIMATED COAL ASH PRODUCTION AND UTILIZATION IN 2000 (IN MILLION TONNES) [1]**

IV. HIGH VOLUME FLY ASH (HVFA) CONCRETE

Malhotra et al [6, 11] have initiated in the late of 1980s the development of HVFA concrete using conventional materials and technology. They have shown that it is possible to produce high performance concrete mixtures containing 50-60% fly ash by mass of the blended cementitious material.

The typical characteristics of the HVFA mixtures are [6]:
- The use of 50-60% by mass of class F fly ash of cementitious materials
- The use of low water content, generally less than 130 kg/m³
- Cement content nor more than 200 kg/m³ of concrete
- Very low dosage of superplasticiser, if needed.
- Low water to cementitious materials ratio of 0.30

HVFA concrete shows excellent mechanical properties, and it is still gaining significant increase in its strength development at least until 1 year due to the pozzolanic reaction and it shows better durability compared to normal Portland cement concrete [6]. The successful applications of the HVFA concrete into practice have been reported [12, 13].

V. FLY ASH-BASED GEOPOLYMER CONCRETE

Another noted achievement in the use of fly ash in concrete was the development of geopolymer concrete. In this case, no Portland cement is used, as it is totally replaced by the geopolymer paste. Fly ash can be used as the source material for the geopolymer paste. In this case, fly ash, which is rich in aluminium and silicon oxide, chemically reacts with the alkaline solutions to form inorganic polymeric binder called geopolymer.

Geopolymer technology has been coined by Davidovits et al [14-16], mainly using calcined kaolin as the source material. Since then, many other possible materials have been investigated its potential to be the source material for geopolymer [17]. Fly ash was found to be one of suitable source material for geopolymer.

The development of fly ash-based geopolymer concrete has gained significant advancement. It is possible to manufacture fly ash-based geopolymer concrete using the common technology to produce normal Portland cement concrete [18, 19]. Its shows excellent short term and long term properties, as well as its durability in the sulphate environment [20-22].

The application of fly ash-based geopolymer concrete into structural members has been investigated, i.e. as columns, beams, railway sleepers, walls as well as sewerage pipes [23-26]. It was reported that reinforced geopolymer concrete structures behave in similar manner as those of normal Portland cement concrete. Research to further investigate the behaviour and properties of this ‘newly’ construction material is on going in many different parts of the world.

VI. CONCLUDING REMARKS

One most possible way to make concrete ‘greener’ construction material is to reduce the use of Portland cement. With the abundant availability of fly ash worldwide, it has potential to substantially replace the amount of Portland cement needed for making concrete.

Among the most substantial applications is the use of fly ash into HVFA concrete, which is possible to replace 50-
60% by mass of Portland cement by fly ash, and in fly ash-based geopolymer concrete to totally replace the use of Portland cement in concrete. These two ‘newly’ construction materials have shown excellent material characteristics and properties, as well as durability. Thus, fly ash may play an important role to make concrete ‘greener’ construction material.

VII. REFERENCES

3. ACI Committee 232, Use of Fly Ash in Concrete. 2004, American Concrete Institute: Farmington Hills, Michigan, USA. p. 41.