Coal Use and Fly Ash Disposal in Israel
Henry A. Foner and Thomas L. Robl
UK Center for Applied Energy Research

BACKGROUND
Traditionally all electric power in Israel has been generated from heavy fuel oil. However, the oil crisis of the 1970's and the fall of the Shah of Iran in 1979 so disrupted the traditional supplies of fuel, that the Israeli government decided to diversify its sources of power. For this reason the Hadera power station, which was under construction at that time, was modified to be run on either coal or oil. The power station was commissioned in 1982 and from that time on, all new major generating capacity has been based on coal.

In Table 2, however, the alternatives shown here are now either no longer practicable or available. The amount of fly ash that may be added to Portland cement is limited by the Israeli Standard to 10%. Dumping at sea caused damage to some forms of sea life over a limited time period. Figure 1 shows the location and type of electricity generating plants in Israel. All the power stations are on the coast mainly because the only convenient source of cooling water is the Mediterranean sea. Also, all fuel is imported and it is cheaper and more convenient not to have to move solid fuel inland. The coal used is of low sulfur content (<1%) and is imported from a number of countries as shown in Table 1. At Hadera a jetty was built to handle the coal, while the Ashkelon station is supplied by conveyor from a special coal handling facility built at the nearby port of Ashdod.

The population of Israel is increasing rapidly as the country is also becoming more industrialized. Figure 2(a) shows the exponentially increasing demand for electricity and Figure 2(b) illustrates the fuel imports for power production. Small scale use of coal is forbidden in Israel because of pollution concerns. Efforts to interest larger industrial concerns in the use of coal have been made but only with limited success; general industrial use is currently only about 30,000 tons per year.

From the beginning of coal imports, the question of what to do with the resulting ash has been under much discussion. Many possible solutions have been suggested, including such unusual ones as building islands off the coast to increase the amount of land available for building. What has in fact been done is shown in Table 2. However, the alternatives shown here are now either no longer practicable or available. The amount of fly ash that may be added to Portland cement is limited by the Israeli Standard to 10%. Dumping at sea caused damage to some forms of sea life over a limited time period.

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Figure 1. Electricity generating plants
Coal Use, (continued)

area and has been forbidden by the Min-
istry of the Environment; also there is no
more room around the power stations to
build embankments. The Ministry of the
Environment has also been reluctant to
approve the use of ash as landfill (or, for
that matter, to dump it in embankments
near the power stations) because of the
possibility of contaminating the shallow
drinking water aquifers with toxic trace
elements leached out of the ash.

By the year 2001, Israel will produce
about 1,300,000 tons of ash annually
and of this, only about 600,000 tons can
be used by the cement industry under
the present regulations. The question is
then, what to do with the rest? It is this
question that we address in the remain-
der of this article.

FLY ASH

About 85% of the ash produced in Israel
is “fly ash,” which is recovered from the
power station chimneys (rather than from
the boilers) and as this contains most of
the trace elements, it is the major portion
of the ash disposal problem. We studied
two representative samples of Israel fly
ash at the CAER this year. These samples,
called South African (SA) and Colombian
(CO) from their approximate source
types, were prepared by the “Coal Ash
Administration” set up in Israel to inves-
tigate problems of ash disposal.

The starting point of our study at CAER
was the assumption that coal fly ash is a
potentially valuable material and that it
should not automatically be treated as a
waste product that must be disposed of
at considerable cost. Worldwide, there
are numerous examples of economi-
cally beneficial fly ash utilization and the
situation in Israel seems to us to be
another promising case.

The type of fly ash available in Israel is
classified by the ASTM as a class F mate-
rial. Class F fly ashes are derived from
relatively high grade bituminous or
better grade coals and have low calcium
contents. This type of fly ash is principally
composed of small (10 m or less) glassy
aluminosilicate spheres. The latter are
formed by the rapid cooling of the mol-
ten mineral matter in the pulverized coal
used in the power station boilers. The
principal property of these spheres is that
they are pozzolanic, i.e. they react with
free lime (which is present in hydrated
Portland cement). A good quality
pozzolan improves many of the impor-
tant properties of concrete, particularly
its durability and permeability. By tying
up the free lime, the pozzolan reduces
the susceptibility of the concrete to sul-
fate attack, carbonation and chlorination.

In order to market fly ash as a pozzolan,
it should be of good quality and consist-
tent in nature. Many countries have
standards for this purpose and these are
usually very similar to those adopted in
the USA by the ASTM. In our study of
these fly ashes we have determined the
chemical mineralogical and technical
properties of the two representative
samples. In order to test the possibility
of beneficiating the original materials
we have also carried out the same tests on
various sized fractions of the ash.

SOME TEST RESULTS

Table 3 shows the particle size distribu-
tion of the original samples and also the
carbon content of the various size
fractions. It can be seen that the larger
sized fractions contain large propor-
tions of carbon. Table 4 shows the
carbon content of the fly ash after
passing through the specified sieves.
The carbon content of the ash is
significantly reduced by removing the
>100 mesh or >200 mesh material. With
the gradual introduction of low-NOx
burners, the amount of residual carbon
in the fly ash is expected to increase, so
carbon removal will become a more
important factor in ash beneficiation.
Although carbon is undesirable in the
ash (as it adsorbs air entraining agent),
it can be used for fuel or as an industrial
adsorbent when separated.

The principal technical test of the suitabil-
ity of a fly ash for use as a pozzolan is the
Strength Activity Index (SAI). This is an
accelerated test which compares the com-
pressive strengths of two cement/sand
mortars; one made with an Ordinary Port-
land Cement (OPC) and the other made
with same OPC but with 20% of the
cement substituted by fly ash. Table 5
shows the results obtained on the origi-
nal Israel ash samples and on various size
fractions obtained from them by careful
dry sieving.

Both raw ash samples give SAI values
greater than the minimum required by
the ASTM standard (75%), with
increasing values as the coarse fraction
is removed. The South African sample is
particularly good. Table 6 lists a number
of other chemical and technical param-
eters referred to in various ASTM
standards and the results obtained in
tests on the representative ash samples.

Table 1. Sources of Coal Imported into Israel in 1997

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of Mines</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>8</td>
<td>50-52</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>3-4</td>
<td>15</td>
</tr>
<tr>
<td>Colombia</td>
<td>2-3</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of Mines</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>4-5</td>
<td>11</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1</td>
<td>5-7</td>
</tr>
</tbody>
</table>

Table 2. Amounts of ash produced, utilized and disposed of in Israel: Total and recent years (thousands of tons)

<table>
<thead>
<tr>
<th></th>
<th>1993</th>
<th>1994</th>
<th>1995</th>
<th>1982-95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Production</td>
<td>640</td>
<td>650</td>
<td>735</td>
<td>6060</td>
</tr>
<tr>
<td>Utilization/disposal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement production</td>
<td>420</td>
<td>440</td>
<td>630</td>
<td>3910</td>
</tr>
<tr>
<td>Embankments</td>
<td>150</td>
<td>160</td>
<td>20</td>
<td>1120</td>
</tr>
<tr>
<td>Disposal at sea</td>
<td>70</td>
<td>50</td>
<td>85</td>
<td>1030</td>
</tr>
</tbody>
</table>
and their various size fractions. The maximum or minimum values allowed in the standards are also shown.

**DISCUSSION**

The test results show that the original samples are good quality Type F fly ashes. The SA ash is better than the CO. However, relatively simple separation processes (such as air or hydraulic classification) would produce a <200 mesh product which should be more marketable and would have the added advantage of supplying products which could easily be blended to give particular desirable properties. Some possible uses of fly ash which might be particularly suitable for Israel are listed in the next column. Although some of these uses simply replace existing materials with fly ash, others could be the basis of completely new industries. One or more of these uses might entirely solve the environmental and economic problems of ash disposal in Israel. This approach which utilizes the natural pozzolanic properties of the material seems preferable to more “exotic” approaches such as the extraction of aluminum or trace elements.

**Possible Uses**

- A pozzolan for cement in addition to the amounts already used. In large scale projects such as dams, ports, etc., the proportion of ash that can be used is considerably more than the approximately 20% which is routinely added to OPC in the US. This has special importance in reference to the current “Peace Process” in the Middle East as many large scale construction projects are planned, especially in the Gaza area. The use of fly ash in these projects would represent a considerable money savings to all the parties involved. It should be noted that the Ashkelon power station is situated very close to the Gaza strip.

- Used as a replacement for the fine aggregate (sea sand or machine-ground sand) in concretes and mortars.

- As a raw material for light-weight aggregate production. Some commercial systems are available for this purpose.

- As a constituent of light-weight aerated concrete, especially for construction of insulating building blocks. These could replace many of the low-fines concrete blocks used presently.

- As a constituent of “flowable fill” for filling trenches, and surrounding insulation in building basements, shelters, foundations etc.

- Export of fly ash. The Middle East region is lacking in good quality pozzolans. Good quality fly ash can be sold for up to $20/ton in many markets and for considerably more in the Red Sea States.

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**Table 3. Size fractions of the ash components and the percentage of carbon in each**

<table>
<thead>
<tr>
<th>Size</th>
<th>South African</th>
<th>Colombian</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;100 mesh</td>
<td>4.5</td>
<td>46.8</td>
</tr>
<tr>
<td>100-200</td>
<td>10.0</td>
<td>16.2</td>
</tr>
<tr>
<td>200-325</td>
<td>9.2</td>
<td>4.11</td>
</tr>
<tr>
<td>&lt;325</td>
<td>76.3</td>
<td>2.76</td>
</tr>
</tbody>
</table>

**Table 4. Carbon Content of Classified Ash Samples**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>South African</th>
<th>Colombian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole sample</td>
<td>3.3-4.2*</td>
<td>6.2-7.1*</td>
</tr>
<tr>
<td>&lt;100 mesh</td>
<td>2.90</td>
<td>4.30</td>
</tr>
<tr>
<td>&lt;200 mesh</td>
<td>1.93</td>
<td>2.91</td>
</tr>
</tbody>
</table>

*depending on the sample

**Table 5. Compressive strengths (in psi) and SAI (in %) at 7, 34 and 56 days for various sieve size ash fractions. Note: ASTM requirement for SAI = 75% at 7 or 28 days**

<table>
<thead>
<tr>
<th>Sample</th>
<th>7 day Comp. Str</th>
<th>7 days SAI %</th>
<th>34 day Comp. Str</th>
<th>34 day SAI %</th>
<th>56 day Comp. Str</th>
<th>56 day SAI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>4310</td>
<td>100</td>
<td>6220</td>
<td>100</td>
<td>6900</td>
<td>100</td>
</tr>
<tr>
<td>CO -10 mesh</td>
<td>3540</td>
<td>82</td>
<td>5340</td>
<td>86</td>
<td>6100</td>
<td>88</td>
</tr>
<tr>
<td>CO -100 mesh</td>
<td>3330</td>
<td>77</td>
<td>5440</td>
<td>88</td>
<td>6240</td>
<td>90</td>
</tr>
<tr>
<td>CO -200 mesh</td>
<td>3670</td>
<td>85</td>
<td>5800</td>
<td>93</td>
<td>6500</td>
<td>94</td>
</tr>
<tr>
<td>SA -10 mesh</td>
<td>3770</td>
<td>88</td>
<td>6020</td>
<td>97</td>
<td>6710</td>
<td>97</td>
</tr>
<tr>
<td>SA -100 mesh</td>
<td>4070</td>
<td>95</td>
<td>6170</td>
<td>99</td>
<td>7150</td>
<td>104</td>
</tr>
<tr>
<td>SA -200 mesh</td>
<td>4150</td>
<td>96</td>
<td>6500</td>
<td>105</td>
<td>7460</td>
<td>108</td>
</tr>
</tbody>
</table>

**Table 6. Various Chemical and Technical Parameters based on ASTM Specifications (note: Fineness limit is for Portland Cement)**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Blaine Fineness (m²/kg)</th>
<th>Water requirement (%)</th>
<th>Retained on wet 45 mm sieve</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>SO₃</th>
<th>LOI (%)</th>
<th>Moisture (%)</th>
<th>Multiple Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM Limit</td>
<td>C150-89</td>
<td>C618-89</td>
<td>C618-89</td>
<td>C618-89</td>
<td>C618-89</td>
<td>C618-89</td>
<td>10 max.</td>
<td>3 max.</td>
<td>255 max.</td>
</tr>
<tr>
<td>CO</td>
<td>328</td>
<td>101</td>
<td>25.7</td>
<td>88.4%</td>
<td>0.4</td>
<td>6.8</td>
<td>0.20</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>CO &lt;100</td>
<td>319</td>
<td>99</td>
<td>23.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO &lt;200</td>
<td>322</td>
<td>97</td>
<td>16.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>363</td>
<td>97</td>
<td>20.7</td>
<td>81.2%</td>
<td>0.5</td>
<td>4.0</td>
<td>0.23</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>SA &lt;100</td>
<td>370</td>
<td>96</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA &lt;200</td>
<td>375</td>
<td>95</td>
<td>11.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Some CCBs have been injected into mine refuse disposal site construction. There is a possibility that some CCBs may be used for structural fill in CCB wastes and CCBs to be mixed or, at times, they are delivered to one mine and the coal is shipped from another nearby. Flexibility has been built into our operations to allow for changes that may occur during the term of the contract and for new contracts that may be secured. We have considered many different methods of handling and disposing of CCBs. We utilize CCBs constructively whenever possible, but still have a great deal left over. We understand that there are concerns over the longterm effect of CCBs on the environment and we constantly monitor for changes. Nonetheless, we believe that CCBs will be benign or beneficial in most applications.

Haulback, (continued)

As backhaul operations gain popularity with coal customers, it is becoming necessary for the mine operator to deal with various types, quantities and properties of coal combustion byproducts. Coal-market conditions may dictate the amount of coal sales that will be used to offset the CCBs shipped back to the mine. Whether the CCBs are disposed of or used for beneficial operations has an effect on the handling methods. CCBs may compete with coal refuse for available space. Disposal areas at mine sites must be properly permitted and constructed. This process is time consuming and expensive. CCB volumes may be seasonal and it may be difficult to handle the traffic at peak times.

There can be wide variations in the physical and chemical characteristics of the CCBs produced at different sites. A coal mining company with a number of backhaul customers will have to be able to handle and dispose of the different types of CCBs. Their volume, characteristics, delivery means and schedules must be taken into account when planning the backhaul operation. The effects of one type of CCB on the others may require special handling. Before entering into a backhaul agreement, samples of the CCBs are analyzed for chemical constituents and leaching potential. When CCBs from different sources are handled at the same facility, composite samples are analyzed in the same manner. Once the CCBs reach the mine, the operator must determine the most cost-efficient way to handle the CCBs. Some CCBs have been used for mine reclamation, but the volume of CCBs received may be much larger than the amount needed for reclamation. Most CCBs contain some alkalinity. This makes them potentially useful in mine reclamation. In surface mines, the rock overlying the coal is removed to expose the coal for mining. After the coal has been mined, the CCBs may be placed against the exposed coal seam or on the mine floor to help control acid-water generation after the waste rock has been returned to the pit. At underground mines, CCBs may be mixed with coal processing refuse or placed over refuse for the same purpose. Even when reclamation is not the purpose, it is not uncommon for coal processing wastes and CCBs to be mixed or, at least, placed in the same disposal site. There is a possibility that some CCBs may be used for structural fill in CCB-mine refuse disposal site construction. Some CCBs have been injected into abandoned underground mine works to help support the mine roof and prevent subsidence, but this is expensive and not yet common.

Freeman United Coal Mining Company has been engaged in CCB backhaul operations since 1991. Since that time we have handled over two million tons of CCBs at several locations and we presently have about ten customers using backhaul contracts. Not all of our mines are suitable for CCB disposal, so sometimes they are delivered to one mine and the coal is shipped from another nearby. Flexibility has been built into our operations to allow for changes that may occur during the term of the contract and for new contracts that may be secured. We have considered many different methods of handling and disposing of CCBs. We utilize CCBs constructively whenever possible, but still have a great deal left over. We understand that there are concerns over the longterm effect of CCBs on the environment and we constantly monitor for changes. Nonetheless, we believe that CCBs will be benign or beneficial in most applications.

This brings us to our need for organizations such as the Center for Applied Energy Research. It is important for us to cooperate with these institutions to study the uses and effects of CCBs. It is important that these institutions remain impartial and open to all possible consequences of proposed uses, good and bad. The study and characterization of CCBs has given us insight into their behavior and is useful in planning our operations. Observation of weathering of CCBs has given us information on their stability and ultimate fate in the environment. We need this kind of information for our own use, but it is also important that this information reach the regulatory agencies and the public. With the knowledge that we have gained from the research into CCBs, we can now make informed decisions as to their suitability for our purpose.

Bill Giles has been with Freeman United Coal Mining Company since 1976 and has worked with Coal Ash Handling And Disposal since 1990.

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They’re Back!

The first issue of Energeia in 1997 contained a notice of CAER’s Drs. Apparao Rao and Peter Eklund publishing an article in Science Magazine. Now the two have coauthored an article entitled “Evidence for charge transfer in doped carbon nanotube bundles from Raman scattering,” in the July 17th issue of the prestigious journal Nature. Other coauthors include: Shunji Bandow (Institute for Molecular Science), and A. Thess and Richard Smalley (Rice University).

The authors have shown in this article that both n-type and p-type chemical dopants can be used to increase the electrical and thermal conductivity of the carbon nanotube by a factor of 20 or greater; “ropes” or bundles of nanotubes were investigated and the dopant may reside in the triangular, interstitial channels (between nanotubes) in the bundle.

Congratulations to two of the CAER’s own!

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