OIL SHALE UTILIZATION IN ISRAEL: THE FIRST YEAR OF COMBUSTION DEMONSTRATION PLANT OPERATION

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ABSTRACT. Geological surveys have confirmed the existence of substantial Israeli oil shale reserves. The proven reserves contain approximately 12 billion tons of available ore, and the potential is deemed to be much higher. Economic studies conducted by PAMA indicate promising potential for power generation via Israeli oil shale combustion. Electric power from oil shale appears competitive with power generated from coal fired power plants located along the coast. PAMA's demonstration power plant has been in operation since the end of 1989. Based on the successful results of the first year of operation, PAMA and IEC are now engaged in a pre-project program for a 1000 MW commercial oil shale fired power plant, based on eight 120 MW units; the first unit is scheduled to begin operation in 1996.

INTRODUCTION

Oil shales are sedimentary rocks containing a petroleum-like substance called "kerogen," whose age is estimated by geologists as 70 million years. Oil shale reserves are the only major fossil fuel resource which has been discovered in Israel so far. The shale deposits have been found all over the country, but the largest reserves are in the Northern Negev.

Oil shale exploration in the area began in the 1930's with geological surveys mainly — to locate oil shale deposits. During the fifties and the sixties research activity was begun on oil shale properties. In the early seventies, the Rotem-Yamin deposit was discovered and R&D on combustion technology picked up considerable momentum.

In the late 1970s, under the sponsorship of the Ministry of Energy and Infrastructure (MOEI), the R&D activity in this area significantly increased. The impact of the oil crisis, combined with indications of much larger oil shale reserves, prompted the MOEI and some major Israeli energy companies to form PAMA, a company for commercial exploitation of oil shale in Israel. The financial structure of PAMA is shown in Figure 1.

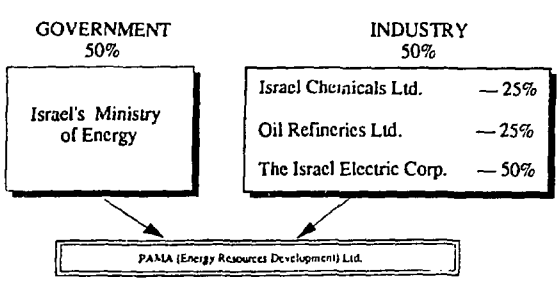

Fig. 1. *Financial structure of PAMA*

BASIC APPROACH AND ACTIVITIES

As is well known, the mineral and chemical industry is typically capital intensive, and the economy of scale has a very significant effect on it. Israeli oil shale is a low quality material with poor energy content (about 14% organic matter). Thus, from the outset it was obvious that the oil shale industry would require large and expensive installations. Nevertheless, given the economic constraint of our country, coupled with the high risk development program envisaged, a cautious strategy was adopted incorporating two main guidelines:

- Disregarding the economy of scale considerations during the first development stages with preference for low risk over economic optimization. So, the development strategy is based on small modular units;
- In the quest for suitable technologies, all traditional stages of development should be implemented.

PAMA's development effort is concentrated on proceeding simultaneously in two main lines of activity:

- The development/adaption of a commercial technology for shale's oil production (retorting);
- The development/adaption of a commercial technology for oil shale combustion.

The R&D program is structured according to the classical three stage development plan:

- Feasibility study, including piloting and techno-economic evaluation;
- Demonstration stage, completed by erection and operation of small scale units;
- Commercial program with erection and operation of full scale commercial facilities.

To date, PAMA has successfully concluded the feasibility stage, meeting the following targets:

- *Reserves*
  Large-scale deposits containing over 12 billion tons of oil shale have been identified and characterized (Figure 2); The oil shale deposits found in Israel are equivalent to 600 million tons of crude oil. Since Israel consumes nearly 11 million tons of oil equivalent (TOE) annually, the nation's oil shale reserves are sufficient to supply Israel's total fuel consumption for 50 years.

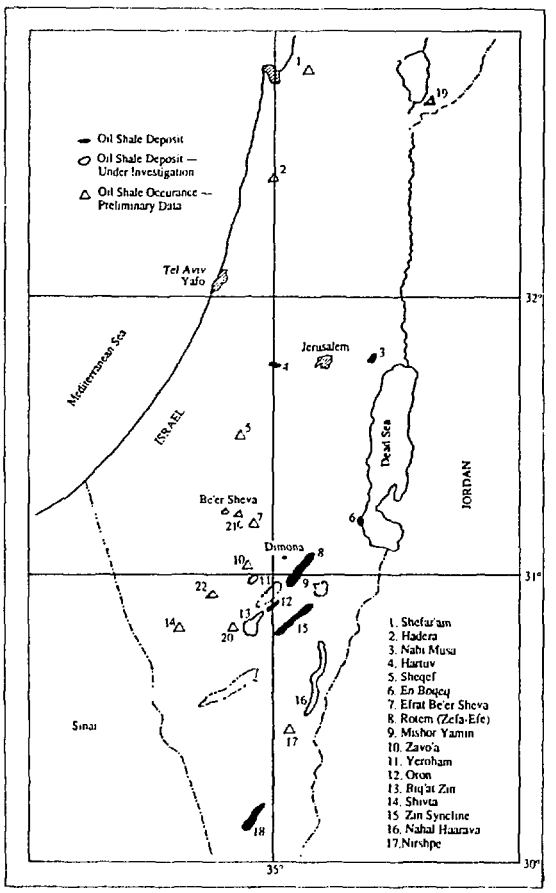

Fig 2. *Oil shale resources in Israel (April 1984)*

The biggest deposit, which has been the most thoroughly studied, is the Rotem-Yamin deposit, formerly called the Ef'e deposit. The northern part of the deposit contains about 2.5 billion tons of mineable ore and the southern part about 5 billion tons of mineable ore.

- *PAMA Center*
  PAMA has established its center adjacent to the Rotem-Yamin deposit. The center contains pilot units, laboratory and support facilities which enable PAMA to examine, adapt and develop technologies suitable for the commercial utilization of Israeli shale.
- *Technology*
  Oil production from shale as well as oil shale combustion have been successfully proven in several laboratory and pilot plants, both in Israel and abroad. It was also found that by conventional methods the upgrading of extracted oil to a higher quality product is possible.
- *Techno-economic potential*
  PAMA identified and tested a number of processes that reached advanced stages of development. Several processes were found to be suitable for synthetic fuel production and direct combustion.

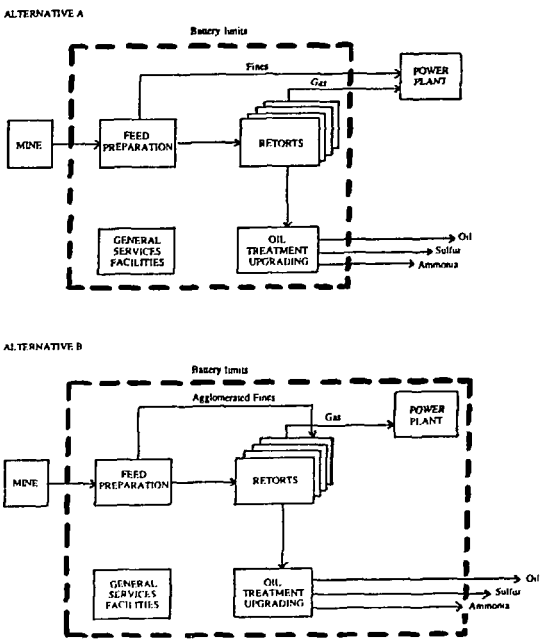

Fig. 3. *Alternatives for oil production by oil shale retorting*

Two extensive techno-economic evaluations were made by PAMA as part of the feasibility study for oil shale utilization. The first study examined a large-scale oil production plant with the following characteristics:

- Oil production rate — 18,000 barrels a day;
- Investment — approximately 1 billion dollars;
- Discount rate — 12%;
- Operating cost — 100 million dollars per year;
- Project duration — 20 years.

This study was carried out in 1982-1983, when oil prices reached levels of 40 dollars per barrel. Results of the study indicated a price range of 30-35 dollars per barrel, demonstrating that such utilization would be technically feasible and under certain conditions economically viable from the national standpoint (Figures 3 and 4).

The second study indicated promising potential for large-scale power generation from Israeli shale. This study was motivated by a comparison showing that oil shales could be provided at approximately half the cost of equivalent coal (Table 1). So, it examined the trade-off between the lower fuel prices and the higher investment and operation costs needed for an oil shale power plant, as compared to coal combustion. The study concluded that a 600 MW station, powered by oil shale would generate electricity at a cost compatible to large scale coal fired coastal power plants (Table 2). Figure 5 is a schematic presentation of PAMA's shales combustion pilot plant.

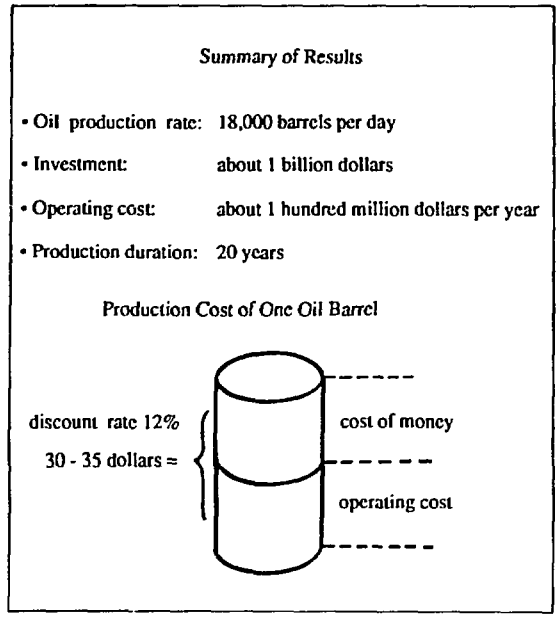

Fig. 4. *Production of oil from shale — an economic evaluation.*

There is another reason to develop the combustion process — a combustion plant, combined with an oil-extraction plant, is an essential condition for large scale oil production from shales, improving the economics of both.

Table 1. *Comparison of coal and oil shale cost*

	COAL	OIL SHALE
Low heating value	6125 Kcal/Kg	700 Kcal/Kg
Price per ton	$ 55-65	$ 2.5

$$\frac{\text{Efficiency of coastal coal plant}}{\text{Efficiency of inland oil shale plant}} \cong 1.34$$

$$\text{Shale cost in equivalent price of coal: } 2.5 \times \frac{6125}{700} \times 1.34 \cong 30 \frac{\$}{\text{ton}}$$

Table 2. *Comparative cost of power generation from coal and oil shale in 600 MW stations. (in cents/KWh, 1986 US $)*

	TYPE OF PLANT			
Discount Rate	COAL INLAND	COAL SEA SHORE	OIL SHALE	OIL SHALE (20% HIGHER INVESTMENT)
12%	5.0	4.2	4.1	4.5
8%	4.2	3.6	3.4	3.7

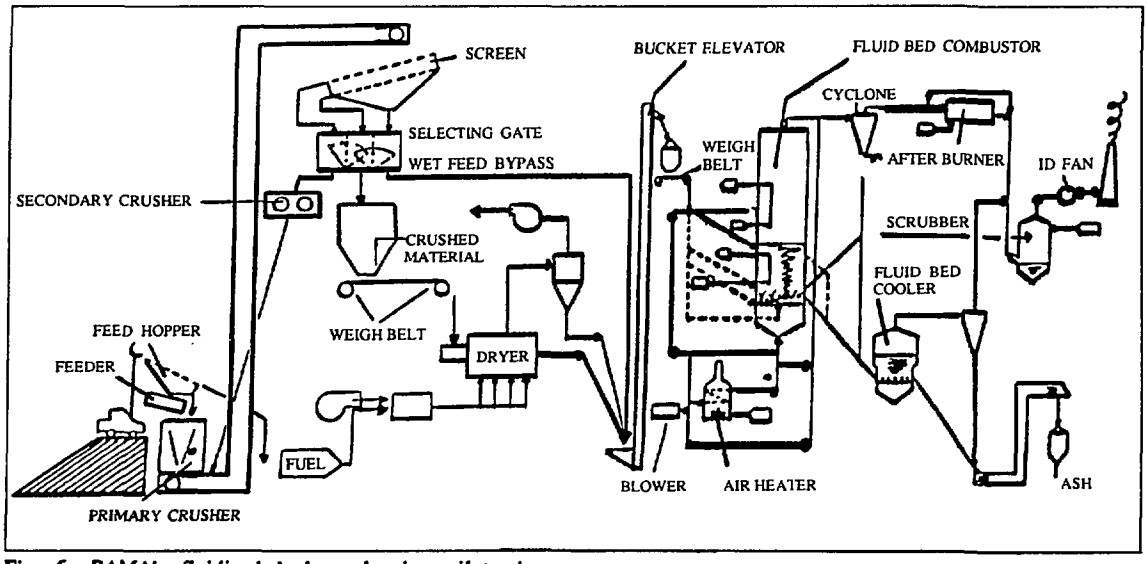

Fig. 5. ***PAMA's fluidized bed combustion pilot plant***

Having concluded the feasibility stage, PAMA began the construction of a demonstration unit for direct combustion of oil shale. Given the recent decline in oil prices, the company decided to postpone construction of the retorting demonstration unit, while concentrating instead on developing an advanced extraction process tailored to the specific properties of Israeli shale.

The objective of the recently constructed demonstration power plant, shown in Figure 6, is to study the combustion of Israeli oil shale at a sufficient scale to resolve the technical and economic issues associated with large scale commercial plants thereby reducing the uncertainties and risks. Table 3 lists the design parameters of the demonstration plant. The plant is producing electricity for the central grid, as well as low-pressure steam, utilized directly by Negev Phosphates Ltd. Figure 7 presents the oil shale fired boiler of the demonstration plant.

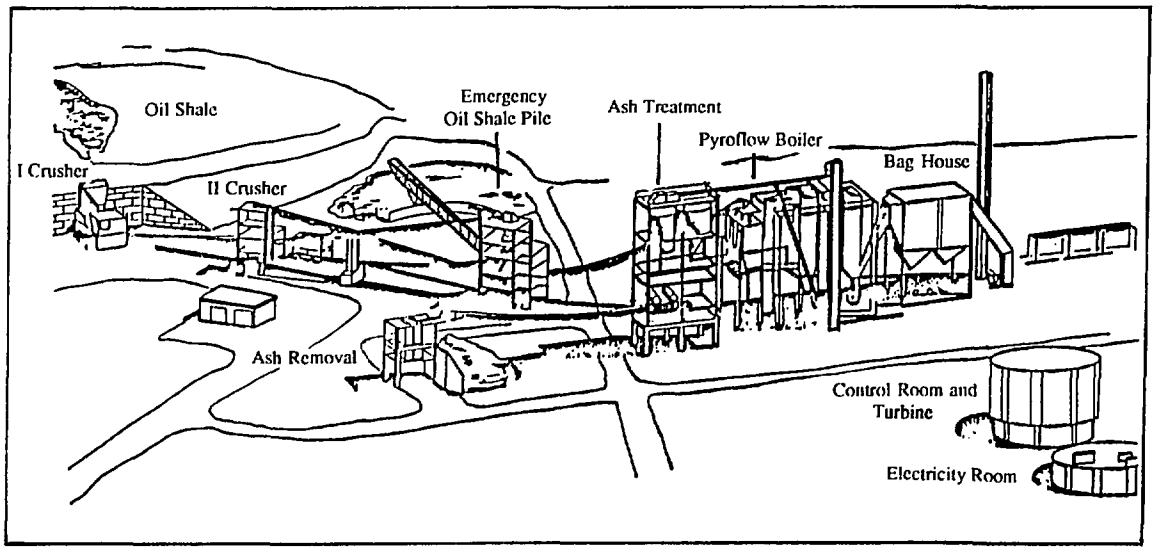

Fig. 6. ***Overview of the demonstration plant for direct combustion of oil shale***

Table 3. *Design parameters of the cogeneration demonstration boiler*

Design Data	
Nominal Capacity	50 TPH
Steam Pressure	43 bar
Steam Temperature	480° C
Total Electricity Output	up to 6.3 MW
Electricity Generation (Net)	up to 4.5 MW
Fuel Data	Oil Shale
Organic Matter	13.6 — 16%
Sulphur	1.1 — 1.7%
Moisture	22%
Ash	44 — 50%
Lower Heating Value	700 — 750 Kcal/kg
Design Performance	
Furnace Temperature	800° C
Flue Gas Exit Temperature	155° C
Feed Water Temperature	105° C
Boiler Efficiency (DIN)	83.7%

PAMA'S DEMO PLANT — FIRST YEAR OF OPERATION

PAMA began the construction of its demonstration plant in August 1987, completing erection on schedule within 24 months (August 1989). Hot commissioning started in September 1989, and revenues from steam sales were already generated about a month later. Electricity production and sales began in February 1990, and since then the plant has been operating continuously.

The following are some results and achievements after more than a year of operation:

- It is possible to combust Israeli shale on a large scale meeting emission standards and operational requirements. A self-sustained and stable combustion is feasible, with no need for additional fuel;
- All facilities connected with the combustion process have been proven;
- Although the fuel used had a lower heating value (LHV) of 700 kcal/kg, combustion was maintained even with 460 kcal/kg of shale's heat;
- The boiler and auxiliary systems have demonstrated great flexibility responding well to sudden changes in steam demand; fluctuations of up to 50% of capacity in a matter of minutes were introduced successfully;
- Actual production of both electricity and steam surpassed the original plans (Figures 8 and 9; Table 4);

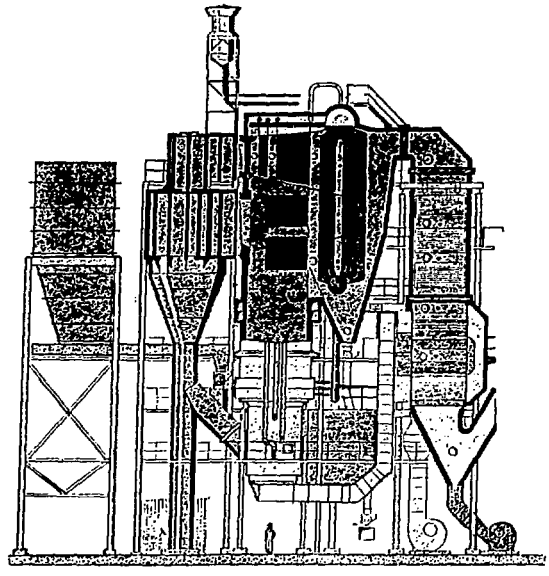

Fig. 7. *Oil shale fired demonstration boiler*

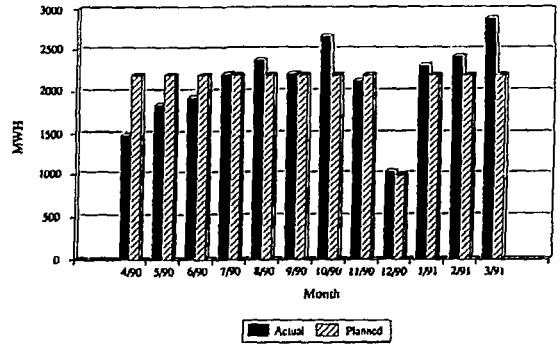

Fig. 8. *Electricity generation (sales). Actual vs. planned*

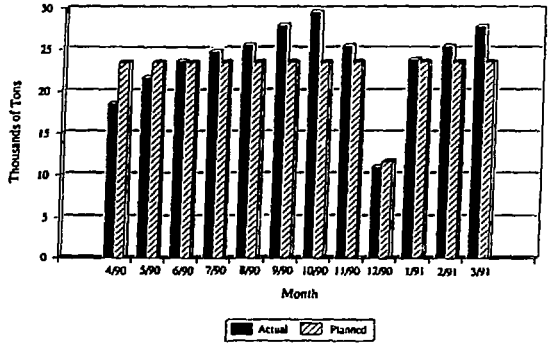

Fig. 9. *Steam generation (sales). Actual vs. planned*

- The demonstration plant performed as follows:
  Maximum capacity achieved — 120% MCR
  Longest uninterrupted run — 90 days
  Combustion efficiency — 99%
  Overall boiler efficiency — 82-84%
  Availability — 90%
  Sulfur capture — 99%
  Emissions — SO_2 - 50 ppm
  CO - 50-70 ppm
  Dust — 70 mg/m³.

Table 4. *Steam and electricity generation (sales).*

First Year of Operation (1990 - 1991)

	Actual	Planned
Steam	284,500 tons	270,000 tons
Electricity	25,456.5 MWH	25,077 MWH

OUTLOOK

Given the demo plant operation results of the first year, PAMA and IEC have recently embarked on a pre-project to a full scale shale fired 1000 MW commercial power plant. The power plant is based at this stage on 8 units of 120 MW each; the first unit should be operational in 1995/6, and the others will be introduced at intervals of one to two years (Figure 10).

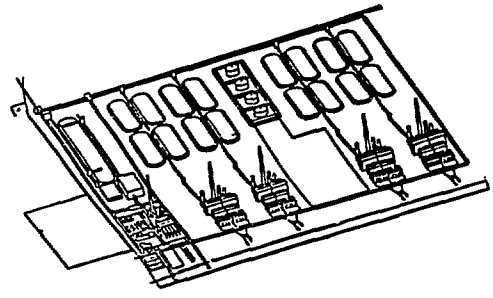

Fig. 10. *Overview of the 1000 MW commercial power plant*

In general, the potential in the field of oil shale combustion is big. Oil shale reserves would be sufficient to supply Israeli electricity demands for the next 160 years at the current level of consumption. The only limitation is whether it can be done economically.

In the oil production field, PAMA plans to construct a pilot plant. The development of advanced catalytic processes, which could significantly increase the yield of top distillates, is progressing rapidly. It will help in making a strategic decision concerning the oil-extraction process.