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RESOURCES GROUP PROGRESS REPORT ON UNCONVENTIONAL OIL STUDIES

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PREFACE

One of the main activities of the IIASA Resources Group is to carry out assessments of energy resources, an activity which was initiated within the Energy Project and subsequent Energy Program. In the field of energy resources, major attention has been devoted to liquid fuels.

In 1976, an important Conference on the "Future Supply of Nature-Made Petroleum and Gas" was organized jointly with the United Nations Institute for Training and Research (UNITAR). During this Conference an extensive review - enhanced by lively discussions - was made of unconventional oil resources. As a follow-up to this Conference, the Resources Group has tried to update available information and has launched its own survey, through the distribution of questionnaires and intensive research in the literature.

This report presents our program up to the end of 1979 and is intended, firstly, as an "informative message" within IIASA and for some international experts and, secondly, as an invitation for comments and/or suggestions on the way in which this work should be continued.

Compared to a mere assessment of unconventional oil reserves and/or resources, this report also illustrates our growing interest in the systems aspects of energy in connection with other natural (or human) resources, namely, water, (other) energy, land, materials and manpower, in other words, the WELMM approach. It is clear that the harvesting of these new, unconventional oil resources will be more and more WELMM intensive. This WELMM dependency adds, in a sense, a new dimension to the McKelvey classification box.

CONTENTS

The chapter on the Data Base for Unconventional Oil Resources also reflects the growing involvement of the Resources Group in data base development and management. This Unconventional Oil Data Base is, in fact, one part of the larger Oil and Gas Resources Data Base which we are developing at IIASA (using the INGRES Data Base Management System). To my knowledge, this Unconventional Oil Data Base is the first of its kind.

This is mainly a technical report. Economic information is still scarce and changing fast. However, I would like to make a comment on investment figures. For tar sand plants - the only ones to reach commercial development, in Canada figures are around $25,000 - $30,000 per barrel per day additional capacity (1979). This is, no doubt, a high figure. But it is misleading to compare it to much lower figures, such as $7,000 - 10,000 per barrel per day capacity for the North Sea. A North Sea production platform is designed to handle high levels of production for 5 to 10 years before declining to much lower levels over a period of years. An oil sand project is designed to operate at capacity throughout the plant's life - which will probably exceed 30 years. As an example, the Syncrude project's $2.2 billion investment is expected to recover one billion barrels of oil for an investment cost of less than $2.50 per recoverable barrel (compared to $6 - $10 per barrel for the North Sea).

Unfortunately, we cannot yet declare in this paper a world start-up of unconventional oil. But there are growing signs that this could happen shortly now: tar sand plants in Canada, Venezuela's new program for heavy oil, and, most important (although not yet fully clear), the U.S. Synfuel Program. As a result of all this, we felt that this was an opportune time for such a progress report.

Michel Grenon

INTRODUCTION

Since many end uses (especially transportation and petrochemical feedstocks) rely on them, liquid fuels are and will remain for some time, essential to both developed and developing economies. Nevertheless, it is now becoming quite clear that the supply of conventional oil--including both large deposits and those still untapped--is limited. Synthetic liquid fuels and/or unconventional oil will therefore have to be used more and more in the near future. Attention has now turned (at least in official declarations and at conferences) to poorer quality resources such as oil shale and tar sand. In order to develop this larger resource base and to ensure available energy reserves, substantial scientific research and improvement in current technology is required.

This paper aims to enable a better assessment of the importance of these resources over the next few decades. Section I attempts to provide background information on the resources available in tar sand and oil shale. Section II explores the different techniques of oil recovery and section III looks at the problems related to this exploration.

I. RESOURCES

Tar sand is a term commonly used to refer to a sedimentary rock (consolidated or unconsolidated) impregnated with heavy viscous black crude oil or bituminous material which cannot be produced in a well by conventional production techniques. It is difficult to distinguish between tar sand and sands containing "heavy oil". The main difference is that of viscosity. However, other parameters such as °API or impurities may be taken into account. This report refers primarily to tar sand deposits although the third part is devoted to a comparison of the exploitation of these deposits with those of oil shale.

Oil shale is defined as a fine textured sedimentary rock containing organic matter known as "kerogen". The kerogen is predominantly derived from algae, spores or pollen, and is usually insoluble in ordinary petroleum solvents. When this shale is heated the kerogen is converted both to gas and heavy oil that can be upgraded to syncrude. Oil shale deposits which yield at least 10 gallons (3.8 wt%) of oil per short ton of shale are considered to be the lowest boundary of oil shale. (In the United States the gallon per short ton is the unit commonly used for the oil content of oil shale. To obtain this value as a weight percentage we must divide one gallon per ton by 2.66).

It is generally agreed that potential hydrocarbon reserves in oil shale or tar sand are very large. Even non-experts in this field have heard of the supergiant deposits of tar sand in Athabasca or oil shale in Colorado.

Over the last few years, there have been many attempts to estimate the importance of these resources and to make a breakdown by country. Many studies have been made, for example, Duncan and Swanson (1965), Matveyev (1974), and Donnel (1976) have made studies on oil shale and Phizackerley and Scott (1967), Walters (1973), Bowman (1976) and Meyer (1979) have made studies on tar sands. Unfortunately the majority of these studies are not independent and do not rely on a specific survey for a country. Thus the literature is full of data that amounts to a "regurgitation of somebody else's data". Resource exploration has not been as intensive as it has been for crude oil or gas, for example. The Colorado oil shale deposits, where the exploration program consisted of surface investigation (aerial photography, photogeologic and surface geologic mapping) and subsurface investigation (interpretation of data from core hole lithologic logs and geophysical logs) was an exception. Very often exploration has been limited to visual observations of surface outcrops and seismic exploration or electric log are seldom used. For this reason many countries do not have definitive data and this makes global figures of potential resources somewhat misleading in as much as they aggregate good data from the U.S.A., Canada and Cental America (essentially Venezuela) with poor to very poor data from other regions.

The Resources Group in IIASA, having organized (jointly with UNITAR) the Conference on the Future Supply of "Nature Made Petroleum and Gas" in 1976 at Laxenburg, decided to launch its own updating survey on Unconventional Oil Resources in order to make an independent assessment of their potential. In order to include findings of the most recent research done in different countries since the 1975 crisis, questionnaires were prepared and sent out to institutes (public or private) in many countries. The first answers seemed full of promise but we have to recognize that results obtained are still far below expectation. It is difficult to say whether this is due to a lack of knowledge or to a lack of interest. Tables I.1 and I.2 show all the available information. The first column summarizes the studies of Duncan and Swanson for oil shale and the study of Phizackerley for tar sand. The last column gives more up to date information. It is obvious that most sources of data are still very old and that improvements are, as yet, not very significant. However, it is interesting to note that in known areas, and in areas where knowledge has been further increased, there has generally been an increase in the size of estimates.

The important question, of course, is whether this could be expected to be a general phenomenon, e.g. that deposits have been very conservatively estimated in the past (sometimes by as much as a few decades) and that more recent and better assessments will upgrade them. It is premature, and unfortunately not yet possible, to give a definite answer to this question. However, the following examples give some preliminary information.

Table 1.1. Tar Sand Resources

		P.H. PHIZACKERLEY & L.O. SCOTT 1967 (1)			UP TO DATE INFORMATION		
COUNTRY	NAME OF DEPOSITS	KNOWN RESOURCES 10^6 bbl	DATE OF ESTIMATION	SOURCE OF INFORMATION	KNOWN RESOURCES 10^6 bbl	DATE OF ESTIMATION	SOURCE OF INFORMATION
CANADA	Athabasca	625900	1963	Alberta Oil &	869000	1978	Outrim and Evans
	Cold Lake			Gas Conserva-	270000	1978	"
	Wabasca	33400	1963	tion Board	119000	1978	"
	Peace River	51500	1963	"	92000	1978	"
	Melville Island	?		-	50-100	1967	7th World Petroleum Congress
U.S.A.	Asphalt Ridge	900	1965	Ball Ass. Ltd.	1048	1979	Campbell
	Sunnyside	500	"	"	3500-4000	1979	Campbell
	Whiterocks	250	"	"	125	1973	Ritzma
	Edna	165	"	"	175	1979	Hallmark
	Peor Springs	87	"	"	4000-5000	1979	Campbell
	Santa Rosa	57	"	"	*57*	1965	Ball Associates Ltd.
	Sisquoc	50	"	"	106	1979	Hallmark
	Asphalt	48	"	"	*48*	1965	Ball Associates Ltd.
	David Dismal Crack	22	"	"	*22*	1965	"
	Santa Cruz	20	"	"	*20*	1965	"
	Kyrock	18	"	"	*18*	1965	"
	Hill Creek		"	"	1160	1979	Campbell
	Tar Sand Triangle		"	"	12500-18000	1979	Campbell
	Circle Cliff		"	"	1300	1979	Campbell
VENEZUELA	Orinoco	200000	1964	-	693000	1967	7th World Petroleum Congress
	Guanoco	62	1950	Oil Gas Journal	*62*	1950	Oil Gas Journal
MALAGASY	Bemolanga	1750	1954	Kent-Rapport BP	22000	1962	SPM Documents
TRINIDAD	La Brea	60	1961	Kugler	2000	1979	Edmonton Conference
ALBANIA	Selenizza	371	1967	Phizackerley			
RUMANIA	Derna	25	?	?	*25*		
U.R.S.S.	Cheildag	24	?	?	*24*		
	Olenek				8000	1977	Desmaisons
	Melekess				123000	1977	"
	Siligir				13000	1977	"

Table I.2. Oil shale resources

		DUNCAN AND SWANSON 1965			UP TO DATE INFORMATION		
	COUNTRIES	KNOWN RESOURCES 10^6 bbl	DATE OF ESTIMATION	SOURCE OF INFORMATION	KNOWN RESOURCES 10^6 bbl	DATE OF ESTIMATION	SOURCES OF INFORMATION
EUROPE	Austria	no data	no data	no data	8	1974	Matveyev
	Bulgaria	125	1962	Jaffe	125	1962	Jaffe
	France	425	1951	Gurthrie	7000	1978	Annale des Mines "Schistes bitumineux francais"
	Germany	2000	1965	Duncan	2000	1965	Duncan
	Great Britain	1000	1962	Jaffe	3500	1975	McLeod Matthews
	Italy	35000	1951	B. Giunta	10000	1979	Agip - ENI
	(Sicily)				63000	1978	Michel Monnier
	Luxembourg	700	1952	OEEC	700	1952	OEEC
	Poland	No data	No data	No data	48	1974	Matveyev
	Spain	280	1958	Gejrot	280	1958	Gejrot
	Sweden	2500	1965	Duncan	3160	1979	Geological Survey of Sweden
	Czechoslovakia	6	1938	Schulz	No resources	1979	National Geological Board
	Turkey	18	1965	Duncan	Great potential	1979	Turkish Petroleum Corporation
	Yugoslavia	210	1952	Organization EEC	>1540	1978	Politika Belgrade, February, May 1978
	U.S.S.R.	112600	1965	Duncan	112600	1965	Duncan
SOUTH AMERICA	Brazil	802000	1965	Duncan	802000	1965	Duncan
	Argentina	400	1962	Parker	400	1962	Parker
	Chile	21	1936	Department of Mines & Petrol	21	1936	Department of Mines & Petrol
ASIA	Burma	2000	1924	Great Britain Mineral Resources	2000	1924	Great Britain Mineral Resources
	China	28000	1965	Duncan	28000	1965	Duncan
	Israel,	20	1960	Nir	See p - [illegible]	1979	Ministry of Energy
	Jordan, Syria	50	1959	McKelvey	50	1959	McKelvey
	Thailand	800		Duncan	800		Duncan
AFRICA	Malagasca	No data	No data	No data	32	1974	Matveyev
	Morocco	No data	No data	No data	95000	1979	Moussa Saudi Revue de l'Energie
	South Africa	130	1937	Petrick	130	1937	Petrick
	Zaire	100000	1958	Gejrot	100000	1958	Gejrot
AUSTRALIA & NEW ZEALAND	Australia	252	1951/1962	Kraemer/Jaffe	600	1976	Lindner, Dixon, APEA Journal 1976
	Tasmania	19		Duncan/Swanson	19		Duncan/Swanson
	New Zealand	252	1940	Willet & Willman	No current interest	1979	New Zealand Geological Survey
NORTH AMERICA	U.S.A.	2000220	1965	Duncan	2000220	1965	Duncan
	Canada	44030	1948	Canadian Department of Mines & Resources	44030	1948	Canadian Department of Mines & Resources
			1924	British Mineral Resources Bureau			

a. Tar Sand Deposits

Canada

In his paper, P.H. Phizackerley mentioned three deposits; Athabasca, Peace River and Wabasca. The total known resources of these three deposits were equivalent to 710800 million barrels. In 1979, referring to a study by Outtrim and Evans, the Geologic Division from the Alberta Research Council gave the following values: 1080000 million barrels for these three deposits, to which we have to add 270000 million barrels for Cold Lake Deposit.

California

Estimates have increased from 270-323 million barrels in 1965 (Ball Associates) to 966 million barrels in 1979 (F.O. Hallmark) through the addition of new deposits, not including two large but conjectural deposits.

Utah

Estimates have grown from 2.0-4.3 billion barrels in 1965 (Ball Associates) to 22.4-29.2 billion barrels (Ritzma) in 1979.

Madagascar

A 1954 British Petroleum study used in Phizackerley's assessment (Kent 1954) estimated tar sand resources at 1.79 billion barrels. A 1962 survey made by the Malagasy Oil Company (Andrianosolo and Co. 1979) arrived at a possible estimate of 22 billion barrels (3 billion toe).

The U.S.S.R.

In 1978, Desmaison in an article in "Oil and Gas Journal" mentioned three deposits in the U.S.S.R.: Melekess, Siligir and Olenek. However, Dr Meyer stressed in his presentation at the Edmonton Conference that resource estimates for the Soviet Union are "unquestionably seriously in error because of the lack of information".

b. Oil Shale Deposits

Australia

The fact that oil shale exists near The Narrows between Rundle Range and Curtis Island, Queensland, has been known for many years. Referring to Jaffe (1962) Duncan and Swanson estimated that the deposit might contain 200 million barrels oil equivalent. A two year campaign of core drilling realized in

1974-1975 by Southern Pacific Petroleum N.L. and Central Pacific Minerals N.L. seems to indicate that in this area there are at least 1200 million tonnes of oil shale (with an average grade of 89 l/t) which contains the equivalent of 600 million barrels.

Great Britain

In 1978, the Institute of Geological Sciences was completing a study of British Oil Shales on behalf of the Department of Energy. The results have not yet been published unfortunately. The United Kingdom has two principal groups of oil shale: the Kimmeridge Clay and the Lothians Deposits. McLeod Matthews in a report published in 1975, having recalled figures from global surveys (10^9 tons of shale, capable of yielding 150 million tons of crude oil) wrote about the Kimmeridge clay deposit. "A maximum theoretical distribution of Kimmeridge shale would perhaps cover about 7500 square miles. Even 25% of this, if it roughly reproduced the characteristics of the proven shales in Dorset, would contain about 3500 10^6 tons of shale, yielding 500 10^6 tons of oil". However, he insisted on the impossibility of the IGS makeing a reliable assessment of the resources because of the lack of data. As for the Lothian deposit, a report published in 1978 by the Institute of Geological Sciences gave the following figures: Total resources amount to 1100 tonnes of shale divided into 120 million tonnes of probable resources, 240 million tonnes of possible resources, and 740 million tonnes of deep resources which are as yet unproven. Only 65 million tonnes of probable resources could be extracted and would yield about 35 million barrels of oil.

France

There are 440 million barrels of oil (shale) resources according to Donnel. However, Combaz thinks that the number is higher. A three year study (1974-1978) including 35 core drilling holes over a broad area east of Paris, identified about seven billion barrels. In the region of Fecocourt, (an area of 36.50 km^2) the resources of oil shale (with a grade of 40 kg/t and restricted to an overburden ratio of about two) represent the equivalent of 400 million barrels.

Israel

Duncan and Swanson reported that the explored parts of the Um Balek deposit were estimated to contain about 20 million barrels of oil equivalent from shale that yields about 12.5 g/st. Recently, the Ministry of Energy of the State of Israel indicated to us that there are three major known oil shale deposits in Israel. Total resources are over 2000 million tons of shale with an average kerogen content of approximately 15%. The oil shale resource is considered as a possible contributor of up to 10-20% of the energy supply in the nineties.

Morocco

There was no estimate by Duncan and Swanson, however, in 1974 Matveyev estimated about 600 million barrels. In 1979 Mouassa Saadi reported that geological studies undertaken since 1970 had revealed two important deposits of bituminous shale: the deposit at Tinahdit, with reserves estimated at more than 20 billion tons with an average oil content of 8% and the Tarfaya deposit with reserves of the order of 200 billion tons with an average oil content of approximately 6% wt which represents a total of 95 10^9 barrels of oil equivalent.

New Zealand

Exploratory drilling in New Zealand between 1961 and 1962 has changed the status of the Nevis oil shale deposit from one that was prospectively valuable to one of little commercial interest. The New Zealand Geological Survey confirmed that no further exploratory work is envisaged at this stage and no other exploration work is programmed for any of the other oil shale deposits, mainly because the quantities available are very small.

Sweden

The values given by the Geological Survey of Sweden show a slight revaluation of the resources of deposits in the provinces of Öland and Östergotland (2520 10^6 barrels compared to 1900 10^6 barrels according to Duncan) which give a total of 3160 10^6 barrels of oil equivalent for Sweden.

Turkey

At the Edmonton Conference it was confirmed that Turkey has great potential. However, the country is not well enough equipped to carry out the investigations required for the development of this resource.

Yugoslavia

It is reported that large reserves of oil shale near Aleksinats in South Eastern Serbia have been discovered. Two billion tons have already been proven, with an oil content of 10-12%. This could represent about 1500 10^6 barrels oil equivalent.

All these figures must be considered as indications. Indeed to add to the uncertainty, it is very difficult to get information on the data which were used to obtain these estimations. Did they rely on core drilling programs, analysis of samples or just a survey of surface outcroppings?

II. TECHNOLOGY

For a better understanding of the following chapter on the impacts of unconventional oil extraction and upgrading, it was felt useful to give a quick reminder of the current technologies.

TAR SANDS

All methods of bitumen recovery from tar sand must take into account the main characteristics of these tar sands.

1. Bitumen is too viscous to flow naturally: it lacks mobility or fluidity in its natural state.
2. Oil saturated sand is impermeable. There is no natural communication channel within the oil sand reservoir.
3. Oil sand reservoirs have little or no internal drive energy so that oil recovery requires the application of energy.
4. Oil sand reservoirs are not homogenous and have highly variable unconsolidated heterogeneous mass.

The recovery of bitumen therefore requires methods which change these characteristics. There are two basic types of method (See Figure II.1).

-- Surface mining
-- In situ recovery

The first type of method can be applied to deposits close enough to the surface, perhaps with up to 50m. of overburden. However, in Athabasca for example, this kind of deposit represents only

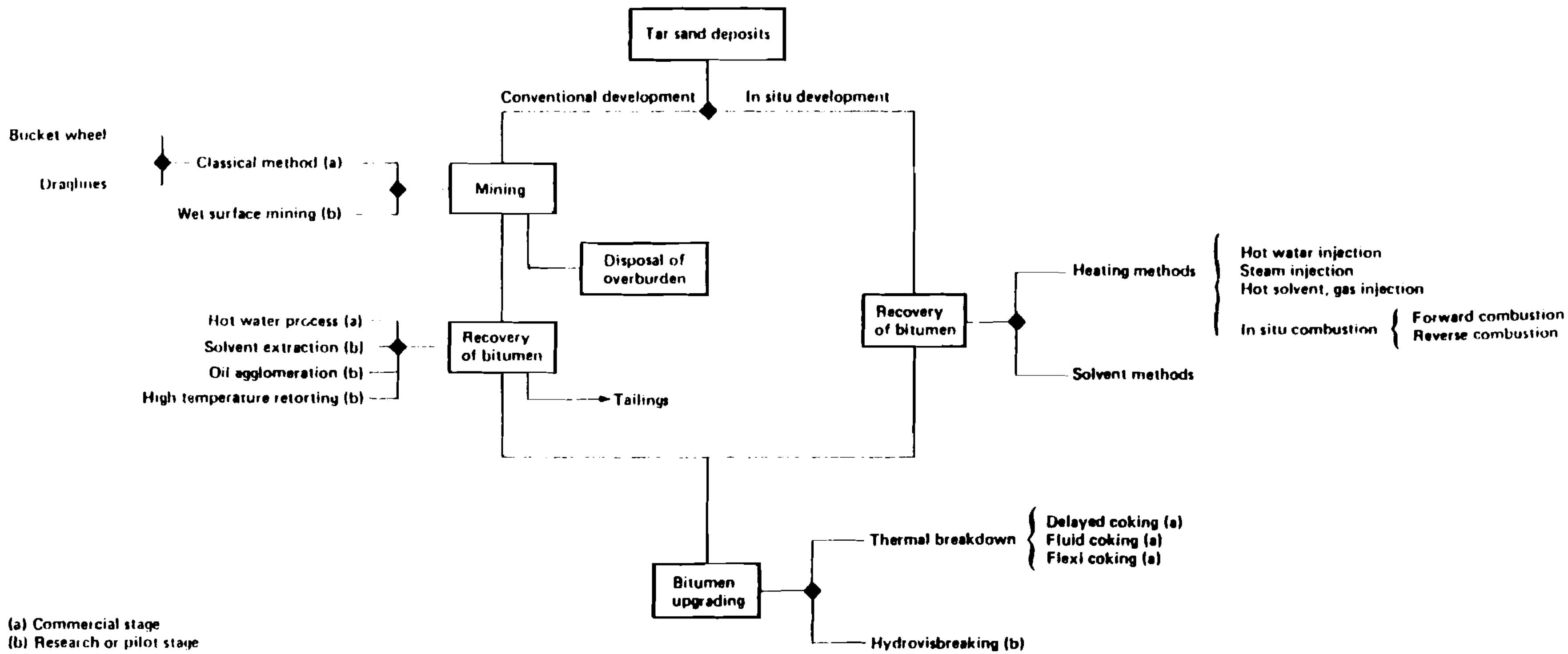


Figure II.1. Tar sand processes

The diatomaceous shales in Sicily are a good example. On the basis of the B. Guinta estimate (1951) Duncan gave the following figures: 35 10^9 barrels of oil in place, of which 7 10^9 barrels are recoverable. In a report published in 1979 (Dalla Casa and Co.) the amounts of bitument in place are thought to be considerably less than the original estimates. On the other hand, Michel Monnier, in his thesis published in 1978, estimated potential hydrocarbons in place to be 63 10^9 barrels. However, Agip confirmed that the very scarce amount of reliable data available makes any quantitative estimation of the potential hydrocarbons in place unreliable (this information was received by personal communication from a manager of The Production Development Department of Agip).

Another very surprising point is that, according to the different global studies, there is no major tar sand deposit in Asia or Africa. This may be due to lack of physical resources or simply to lack of exploration. One may conclude, in fact, that at a world level, the actual figures are really conservative and it is doubtful whether there will be a great change in the coming years. Economic interest in exploiting this type of resource does not seem to be considered large enough by the majority of countries to encourage them to undertake vast exploration programs. Indeed, if the discovery probability is not high, the development of these resources seems to be economically viable only on a very large scale which implies large capital investment. Furthermore, the technology risk is still important. All these reasons explain why in the oil shale field, for example, it is probable that no effort will be made elsewhere before the U.S. really begins to exploit its huge reserves (with the possible exception of Brazil and of Israel, both for strategic reasons)--We would, of course, prefer that this were not the case.

10% of resources in situ. For deposits at greater depths the in situ recovery method appears to be a more suitable approach to exploitation.

Surface Mining

The current surface mining plants (Great Canadian Oil Sands and Syncrude) involve three major operations.

1. A mining operation which consists firstly of the overburden removal and disposal, and then of tar sand mining and transport to a separation facility.
2. An extraction process, i.e. the separation of the bitumen from the oil sand.
3. An upgrading of tar sand bitumen to facilitate pipeline movement to refining centers and to create acceptability as a syncrude feedstock for refining to marketable products.

Until now, the mining operation has been accomplished by the use of large-scale equipment drag-lines or bucket wheels (see III): A new and promising approach is the hydraulic dredging of overburden before oil sand mining. Underground mining is still considered too costly for tar sands.

In the two commercial plants currently in activity, bitumen extraction is accomplished by the Clark Hot Water Process:

According to Spragins (1978):

> Hot water and steam are combined with mechanical energy to transform the tar sand ore into a frothy pulp in separation tanks. The main body of pulp is then pumped to extraction vessels filled with hot water. Oily froth collects on top and is skimmed off, sand passes out of the bottom, and a middling stream is removed and pumped away to secondary recovery cells where additional oil is recovered. The oily froth is collected from the primary and secondary extraction cells and diluted with gas oil and naphta. After having been passed through a centrifugal system the diluted oil is ready for upgrading.

One of the disadvantages of this process is the large consumption of water (see III). That is why efforts are being made to develop some alternatives such as combined water solvent, solvent extraction, oil agglomeration, and high temperature retorting.

The upgrading, i.e. the conversion, of the product bitumen to synthetic crude oil consists of increasing the hydrogen to carbon ratio of the bitumen. This can be accomplished by carbon withdrawal processes such as delayed coking (Great Canadian Oil Sand--GCOS) or fluid coking (Syncrude) or by hydrogen adding processes such as hydrovisbreaking (hydrocracking or hydrotreating).

In the coking process the bitumen is gradually heated to 550°C. At these temperatures, the volatile portions of the bitumen distill and the residue cracks, producing coke and gaseous and liquid products. The liquid product fractions are subjected to hydrodesulfurization.

In the hydrovisbreaking factors, the bitumen is heated and comes into contact with high pressure hydrogen with or without the aid of a catalyst. This process maximizes the yield of liquids and minimizes the yield of gases and coke. On the other hand this process requires more hydrogen and catalysts.

Up to now, economic reasons have often influenced the selection of coking processes for commercial projects but more and more effort is being devoted to the development of new processes such as the Aurabon Process (Universal Oil Production) or the Eureka Process (Mitsui & Co.).

In Situ Mining

Numerous in situ methods for the recovery of bitumen from tar sand have been proposed over the years (See Figure II.1). e.g. hot water injection, steam injection, hot solvent, gas injection, in situ combustion and solvent methods.

However, from the list of the different test projects in Alberta and in Utah (Table II.1 and II.2), it is possible to see that two methods are receiving special attention.

-- the steam injection method
-- the combustion method

The Steam Injection Method

Steam injection can be either cyclic or continuous. Cyclic steam injection or "huff and puff" techniques involve steam injection into a well for a limited period of time followed by a "shut-in" period (soak time) and by production of the same well until a new injection phase is initiated. Steam drive or steam flooding involve a pattern distribution of separate injection and production wells. This method is generally considered as unsuitable for a reservoir which has little or no primary energy.

The Combustion Method

This process involves drilling two wells into the deposit: one for injection of air and the other for the recovery of the product. After ignition a heat wave propagates within the formation due to the combustion of part of the oil in situ with the oxygen in the injected air. The heat of combustion serves

Table II.1. Experimental projects in oil sand deposits in Alberta[1]

DEPOSIT	PROCESS	OPERATOR	NO. OF WELLS	EXPECTED GROSS COST** $ M	START/COMPLETION DATE
ATHABASCA					
Fort McMurray	Steam	Texaco Expl. Canada	52	25	72/80
Gregoire Lake*	Steam/Combustion	Amoco Canada	25	71	73/80
Surmont*	Fracturing	Numac Oil & Gas	1	2	74/80
Mildred Lake	Horizontal Drill.	Petro-Canada	3	5	79/80
NW of Gregoire Lk	Electric/Steam	Petro-Canada	4	35	80/84
COLD LAKE					
Ethel Lake	Steam	Esso Resources	42	5	64/80
May	Steam	Esso Resources	30	10	71/81
Leming	Steam	Esso Resources	82	30	73/--
Ardmore	Steam	Union Texas	15	4	74/80
Primrose Lake	Steam	Norcen	9	14	75/80
Fort Kent	Steam	Worldwide Energy	31	4	76/83
Cold Lake	Steam	Gulf Canada	6	7	76/83
Marguerite Lake*	Steam/Combustion	BP Exploration	17	31	76/81
Beaver Crossing	Steam	Chevron Standard	7	7	77/81
Bourque	Steam	Esso Resources	12	4	77/82
Primrose	Steam	Petro-Canada	1	-	79/79
Muriel Lake	Steam	Worldwide Energy	7	6	80/--
PEACE RIVER					
Cadotte Lake*	Steam	Shell Canada Resources	31	125	77/84
WABASCA					
Wood River	Steam/Combustion	Gulf Canada	34	20	74/79
Pelican	Steam	Gulf Canada	3	2	79/79
CARBONATE					
Buffalo Creek*	Steam/Combustion	Union Oil	5	10	77/81
Chipewyan*	Steam	Union Oil	7	3	74/79

* Projects having AOSTRA participation

** Estimated gross costs for pilot and associated research in period defined by start/completion dates. These costs do not include lease costs or royalties.

(1) Technological Hurdles for Oil Sands and Heavy Oil Development. C.W. Bowman, M.A. Carrigy, Alberta Oil Sand Technology and Research Authority.

Table II.2. Field projects to test the recovery of oil from U.S. tar sands[2]

				RESERVOIR ZONE				
FIELD	OPERATOR	OPERATING PERIOD	PRODUCING MECHANISM	NAME	DEPTH, FT.	NET THICK-NESS, FT	OIL GRAV-ITY, API	OIL VISCOS-ITY, CP
Cat Canyon Santa Barbara Co., California	Getty Oil Co.	6/76-5/81	Steamflood	S1B Sand	2,5000	80	9°	25,000
Marport Monterrey Co., California	Ogle Petroleum Co.	7/77-?	Steamflood	Monterrey Sand	1,406	80	9°-10°	>100,000 @200°F
McKittrick, Kern Co., California	Getty Oil Co.	1979-84	Strip mining and surface extraction	Diatomaceous earth	0-1,2000	NA	13.6°	NA
Northwest Asphalt Ridge, Uintah Co., Utah	Laramie Energy Technology Center, DOE	71-9/82	In situ combustion and steamflood	Rim Rock Sandstone	300-600	10-50	14°	>1,000,000
Paris Valley, Monterrey Co., California	Husky Oil Co.	1/75-1/80	In situ combustion with water injection	Ansberry Formation	840	50	9°-11°	50,000-400,000

(2) Current Activity in Oil Production from U.S. Tar Sands. L.C. Marchant, C.Q. Cupps, J.J. Stosur.

to increase the temperature of the formation, thereby decreasing the viscosity of the bitumen. There are two in situ combustion processes, forward combustion and reverse combustion. In forward combustion, ignition occurs at the injection well and the combustion front propagates to the producing wells in the same direction as the injected air. In reverse combustion, ignition occurs at the production well and air and the combustion zone travel in opposite directions. Whichever method is chosen, the extracted bitumen must also be upgraded.

OIL SHALE

The process of heating the oil shale to obtain the liquid and gas products is known as "retorting". The amount of oil that can be retorted from oil shale deposits ranges from about 4 to 50% of the weight of the rock, or about 10-150 gals of oil per ton of rock.

There are three retorting techniques currently in use (see Figure II.2).

-- Surface retorting
-- True in situ retorting
-- Modified in situ retorting

Surface Retorting

This method is the most commonly used. It consists of mining, crushing and then heating the shale in a retort vessel above ground.

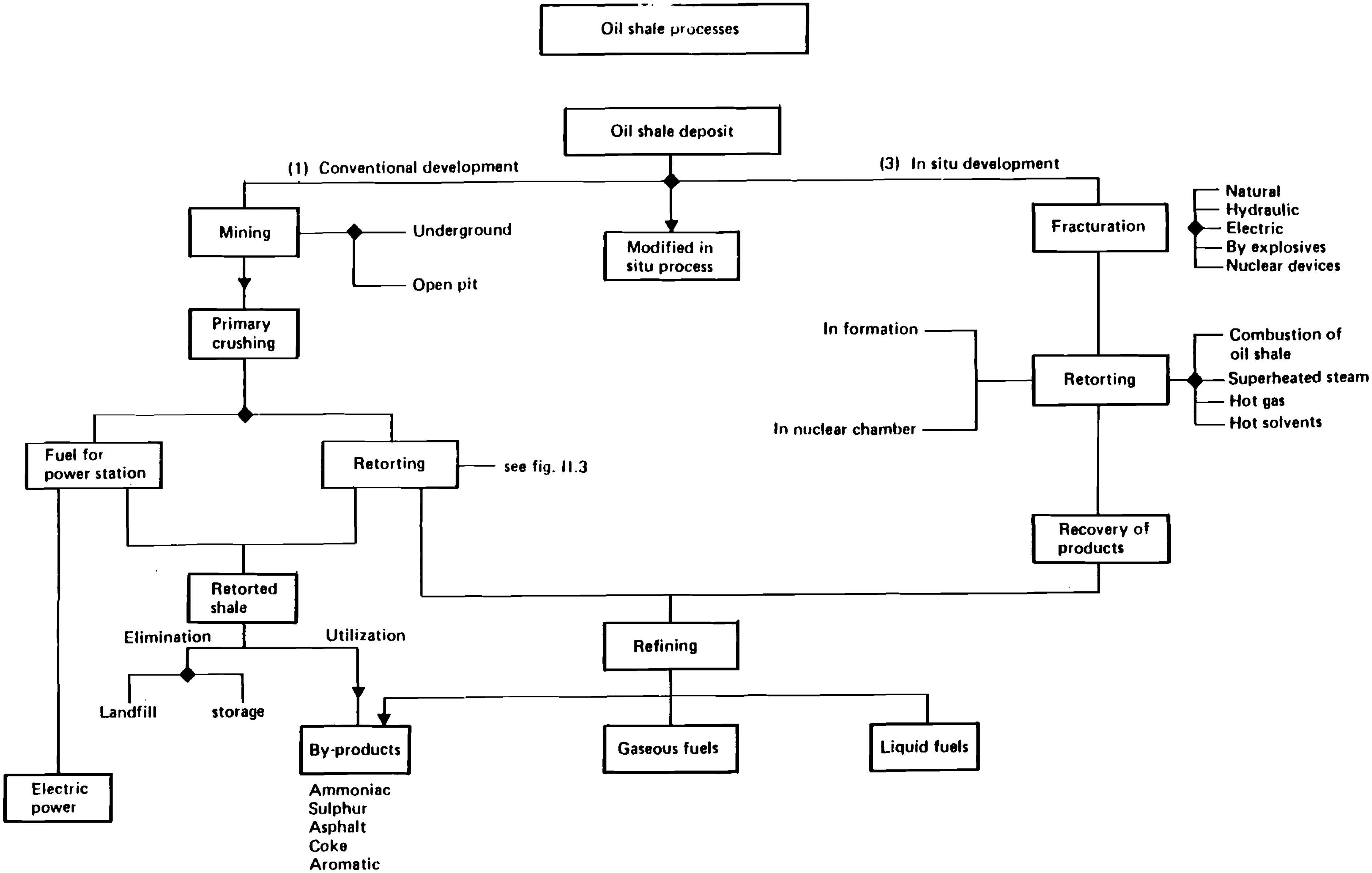
Mining

Surface retorting of oil requires mining of the shale deposit. Oil shale can be mined either by surface or by underground mining. The choice of method is determined by overburden depth, oil shale thickness and grade, deposit size and ground water etc.

Surface mining is a suitable method for large deposits of low to medium grade ore since it permits high recovery of resources and there is room for large and efficient equipment.

Underground mining is well suited to thick, rich and extensive oil shale deposits with overburden exceeding the economic stripping ratio. Various different underground mining methods have been developed.

In the room and pillar method, a portion of the oil shale is removed, forming large 'rooms', pillars are left to support the roof. The chamber and pillar method, which is a modification of room and pillar mining, was designed for underground disposal of processed shale. Processed shale backfilling is started when a chamber is completely mined out. Another method



SOURCE: Burger (1973)

Figure II.2 Oil shale processes

is the block caving method. It is designed for mining thick oil shale sequences. A mining level is driven under the oil shale zone and the roof is blasted to initiate caving. The broken shale developed by subsidence is removed from the mine and retorted on the surface. Processed shale from the surface retorts is dumped into the surface cavity formed. Of course, the resource recovery depends on the mining system used to develop the oil shale deposit (Table II.3)

Retorting

The oil shale must be heated to about 500°C to decompose the embodied kerogen and produce crude shale oil, gas and carbonaceous residue.

There are basically two types of surface retort, depending on the method of introducing heat into the retort (Figure II.3).

1. Internal heating uses the combustion of part of the shale itself to provide the necessary heat;
2. External heating uses heat sources from outside the pyrolysis vessel for their operation. These may be further divided into two categories depending on whether the heat is transferred to the vessel in hot solid or in gases.

Figure II.3 shows the main surface retorting systems corresponding to each category. To date, not one of them has been operated at an industrial level. Of course, the efficiency varies with the selection of a specific retorting system. Table II.4 lists the values of oil yield, based on the Fischer Assay Method.

In Situ Retorting

In situ retorting is currently considered to be an alternative to mining and surface retorting. This method is in the early stages of development. There are three steps to this process:

1. Creation of artificial permeability by fracturing selected shale zones in order to allow the circulation of a heat carrier fluid. Many methods include fracturing by air or water under high pressure, chemical explosives, nuclear devices and electric currents. The need to create artificial permeability is one of the main disadvantages of in situ retorting.
2. Injection of heating-fluid which causes underground pyrolysis in the oil shale zone. The heat source is generated by partial combustion of the in situ oil

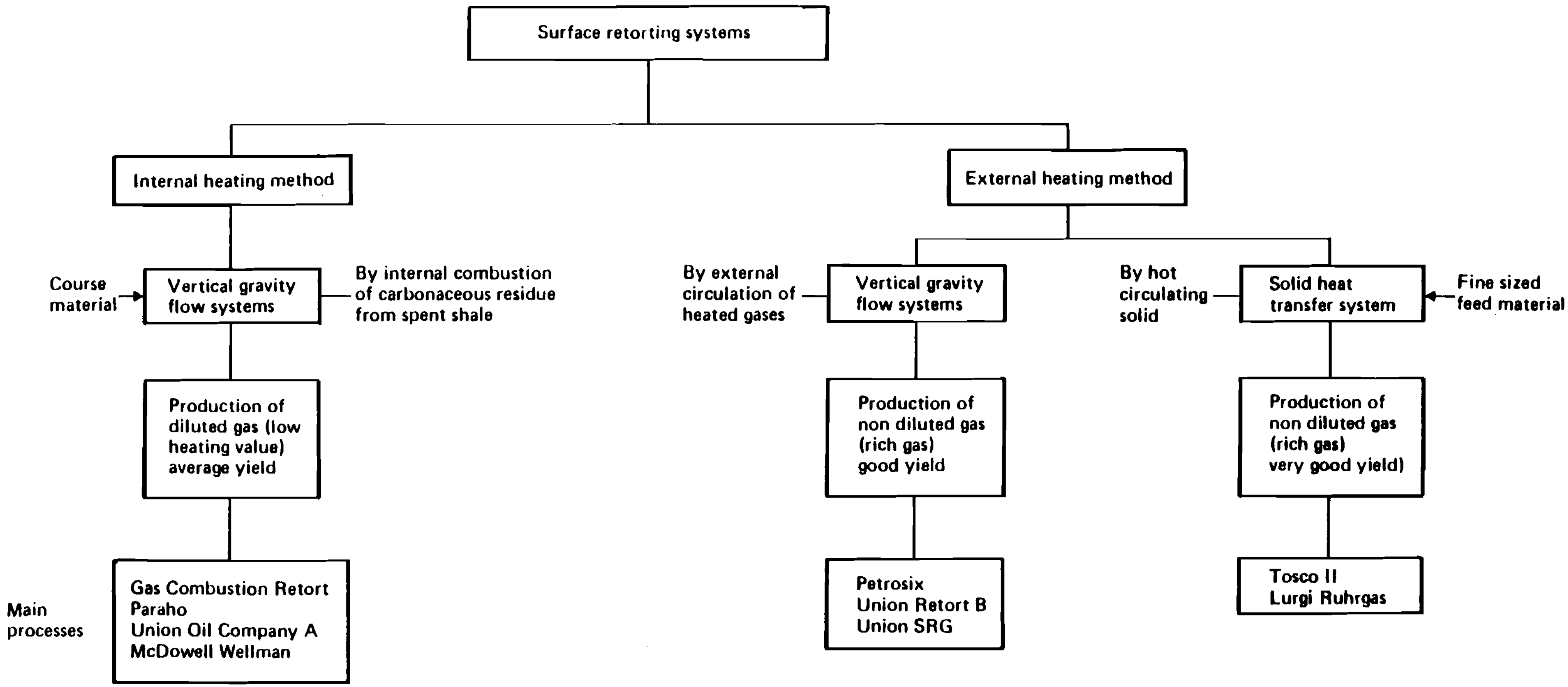
Table II.3. Mining efficiency

	Open pit Mining (1)	Multiple level room and pillar (1)	Room and Pillar Mining (2)	Chamber and Pillar Mining (3)	Sublevel Stopping (3)	Block Caving (3)
Recovery within mining horizon	n.a.	n.a.	60%	52%-64%		
Recovery within entire oil shale sequence	n.a.	n.a.	<60%	31%-39%	52%-82%	90%-95%
Recovery of the total resource within tract C-a	65%	14%	n.a.	n.a.	n.a.	n.a.

(1) Federal Oil Shale Tract C-a: Gulf Oil Corporation and Standard Oil Company, Indiana 1976.

(2) Colony Development Operation, 1977.

(3) Cameron Engineers, 1976.



SOURCE: Burger (1973)

Figure II.3. Surface retorting systems

Table II.4. Retort efficiency--surface retorting

Name of Process	Oil Yield Fischer Assay	Source
Gas combustion Retort	82%-87%	Sladek 1975
Paraho	90%	Sladek 1975
Union Oil Company Retort A	85%	
Union Oil Company Retort B	>85%	
S.R.G.	100%	Sladek 1975
Tosco II Retort		
Liquid hydrocarbons	99%	Hindrickson 1974
Total recovery of C_4 and heavier hydrocarbons	108%	Hindrickson
Lurgi Ruhrgas	102%	Sladek 1975
Petrosix	n.a.	
McDowell Wellman (Superior Oil Company)	n.a.	

Oil Yield Fischer Assay : Retort yields are normally expressed in terms of the Fischer Assay which is the generally accepted laboratory retorting procedure for evaluating oil shale and which consists of the pyrolysis of 100g of crushed rock at 550°C in a steel Fischer retort recovering the condensable elements.

shale initiated by injected air, a mixture of air and recycled gas, or superheated steam etc.

3. Pumping the oil and gases through a pattern of production wells around a central injection well to the surface for upgrading.

Equity Oil has developed a process which consists of injecting either hot natural gas or methane. A laboratory experiment showed that it was possible to extract 80% of oil contained in shale by using gas. Shell Oil Company has carried out some research on injection of steam.

Modified In Situ Retorting

The Occidental Petroleum Corporation has taken a new approach and developed "Modified In Situ Retorting" This process involves mining a portion of the shale bed which is sufficient to produce a void volume of 15% to 30% of the oil shale bed. The remaining shale within the zone to be retorted is rubbled into the mine voids. Retorting is initiated by heating the rubble pile at the top of the retort using an outside energy source. Air, gas or steam is injected at the top of the retort chamber and oil is withdrawn from a dump at the bottom. The retorting efficiency within the in situ chambers is reported to range from approximately 40% to almost 80% of the Fischer Assay Method (see Table II.4). After four and a half years of extensive field testing, Occidental is trying to apply this method on an industrial scale on "Tract C-b" which is one of the two Colorado Oil Shale Lease Tracts of the Federal Oil Shale Leasing Program. Tract C-b is located three miles South of the Piceance Creek Road in Colorado.

III. THE WELMM CONSTRAINTS ON NEW SYNTHETIC LIQUID FUELS

Unconventional resources (tar sand and oil shale) have some common characteristics. Firstly, as discussed in Part I, they are in great abundance and one of the most remarkable characteristics of unconventional resources--as they are currently known--is the predominence of supergiant accumulations. For example, the Athabasca tar sand deposit, which has an area of 23,300 km^2 with 90 billion tons of bitumen in place, is at least one or two times as large as the largest of all conventional fields, Ghawar in Saudi Arabia. The Piceance Creek Basin in Colorado contains about 80 billion tons of shale oil in high-grade oil shale beds.

Another common characteristic of unconventional resources is that, to date, the available technologies seem to be economically viable only on a very large scale, which implies a much greater environmental impact than has been experienced for most other natural energy resource exploitations. Thus the problem of their development cannot by analyzed by looking only at the resource. In fact, environmental and WELMM constraints for large-scale extraction processes (e.g. shortage of water, possible restriction on disturbing land, manpower and material shortage) will probably influence the rate of development more than the ultimate recovery of the resource.

For this reason, an evaluation of the WELMM requirements of different approaches to synthetic liquid fuels would be helpful in revealing the possible constraints or bottlenecks that a new technology may have to overcome to be considered viable. However, in making such an evaluation, one encounters the difficulty of the lack of hard data: as yet, there are only two industrial plants operating for tar sands, while the commercial exploitation of oil shales still remains at the project level. Using the data currently available in published form on operating industrial plants, pilot scale plants, and project/study estimates, a preliminary comparison has been made of the WELMM requirements associated with different synthetic fuel technologies. This provides some useful insights, as discussed below.

WATER

Figure III.1 shows estimates of water requirements for different technologies. In order to compare their relative impact on water resources, the production of one cubic meter of synthetic fuel has been chosen as a reference.

For tar sand, the major part of the water consumption occurs at the conversion stage because of the "hot extraction method" which is currently in use. One disadvantage of this process is that most of the water discharged with the tailings in the tailing pond cannot be recycled (because it contains some solid particles), nor can it be discharged into a river because of the presence of bitumen. For oil shale, the critical steps are the waste disposal and oil shale upgrading, during which 60% of the water is consumed.

It is important to know whether the water resources in the affected regions are sufficient to support such a development. In Colorado the shortage of water will be a serious problem for the large-scale exploitation of oil shales. During the Edmonton Conference (1979), attention was drawn to the fact that the cumulative water requirements for all the projected oil sand mining plants might represent too high a proportion of the total natural flow of the Athabasca River.

ENERGY

In order to build and operate a plant, to harvest the primary energy, and to upgrade and transport it, a great deal of additional energy is needed, particularly if the energy content of the resource is low. For each process, one may give the ratio (R) of energy consumed in resource recovery to energy produced for the market (see Figure III.2).

Table III.1 presents some values for R for different processes. The values of R for all synthetic fuel processes, as well as for the enhanced recovery of oil, are very low especially when compared with those for the production of conventional oil, even in the difficult conditions of the North Sea.

On the basis of the data in Table III.1, we consider it too early to conclude that there is a real difference between the energy efficiencies of the different processes studied here.

On the other hand, if one considers the rate of recovery of the energy in place, it is higher for tar sand exploitation or enhanced recovery than for conventional oil wells: about 65% for the Syncrude (1978) and the Great Canadian Oil Sand (GCOS) plants, 30% to 60% for the different methods of enhanced recovery, compared with an average of 25% for conventional oil. These are certainly the main advantages of the new technologies.

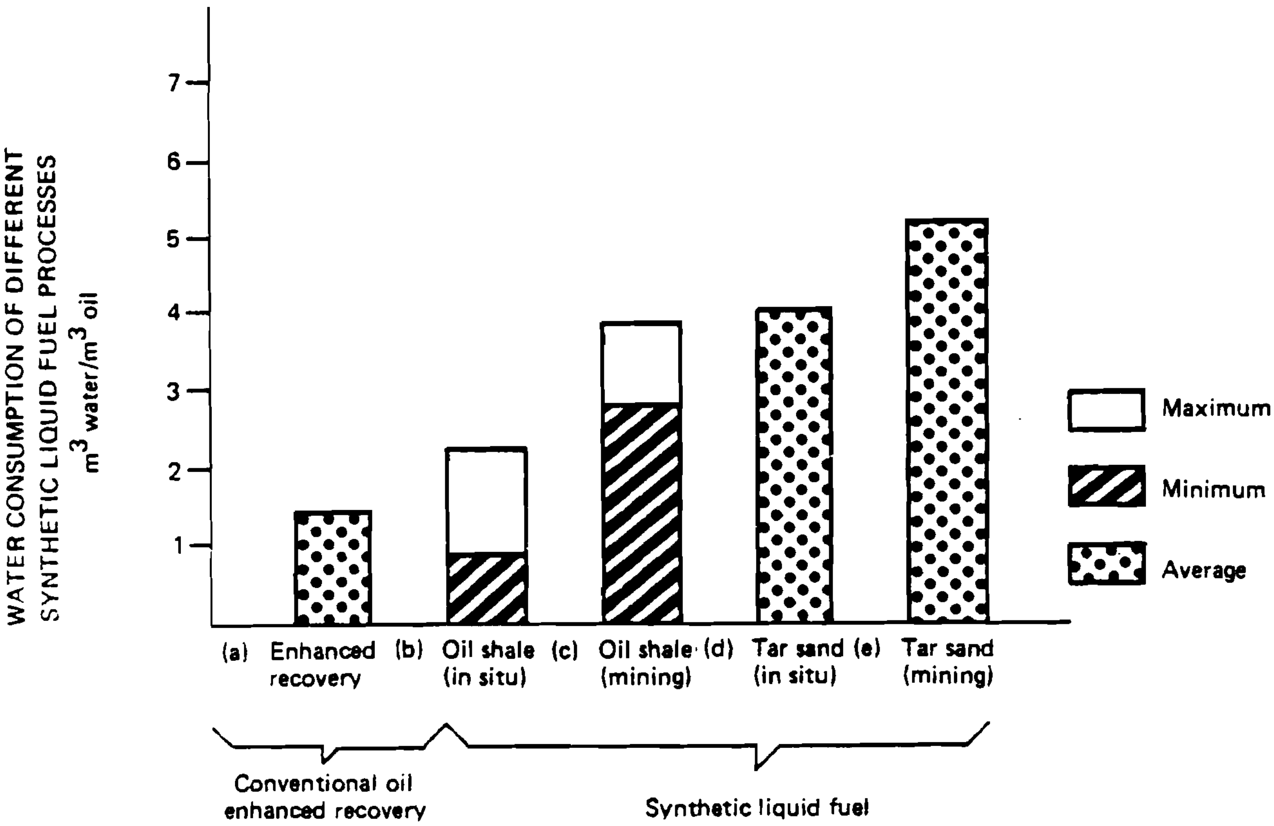
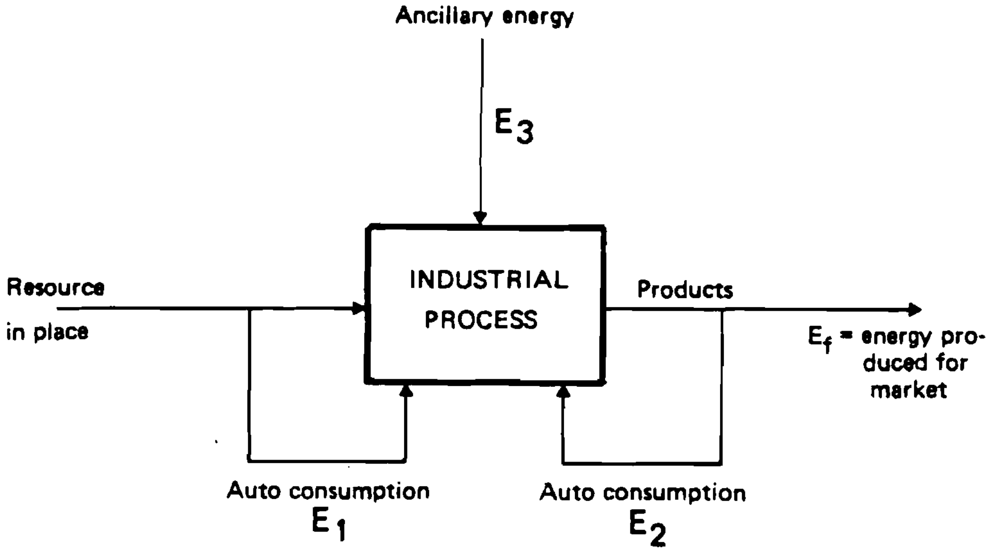


Figure III.1. Water requirements for different synthetic fuel processes compared to enhanced recovery of conventional oil

SOURCES: (a) Bechtel Corporation. 1975, 1976 and 1977; (b) and (c) Crawford et al. 1977; (d) Resources Management Consultants Ltd. 1978; (e) Syncrude Canada Ltd. 1971 and 1973.



$$R = \frac{E_f}{E_1 + E_2 + E_3}$$

Figure III.2. The R ratio of energy consumed in resource recovery to energy produced for the market.

LAND

The processes used for exploiting tar sands and oil shale are all very extensive users of land. They require land for mining development, overburden and waste disposal, construction of facilities, and off-site requirements (e.g. roads).

The land requirements for the tar sand project of Syncrude amount to 70 km^2 (including 11 km^2 for the plant, 30 km^2 for the tailing ponds and about 25 km^2 for the open pit mine area), compared to the land requirements for unconventional oil fields (e.g. Alaska: 180000 b/d fixed land use 0.17 km^2). The same is true of land requirements for oil shale projects. Of course, the amount of land surface required will vary depending on the type of process and on the nature of the raw material.

The figures for the total mined area for different projects, when considered over their lifetimes, are gigantic, as shown in Table III.2. Such land disturbances may result in considerable local impacts such as increases in erosion and sedimentation, changes in soil quality, destruction of vegetation. However, owing to the progress in reclamation and rehabilitation or res-

Table III.1. Values of Energy Ratio R

Tar sand GCOS 45,000 bbl/d[a]	Tar sand imperial 141,000 bbl/d[b]	Oil shale projects[c]	Enhanced in-situ combustion[d]	Oil, North Sea[e]
3.5-4	1.9-2.2	2.2-10	2-8	> 100

SOURCES: (*a*) Heming (1976); (*b*) Resources Management Consultants Ltd. (1978); (*c*) Marland (1977); (*d*) Burger (1979); and (*e*) Klitz (1979).

Table III.2. Land requirements for synthetic fuels (based on open pit mining

	Tar sand 125,000 bbl/d[a]	Oil shale 50,000 bbl/d[b]
Fixed land for surface installations (km^2)	11	1.5-4
Area affected by mining per year (m^2/bbl output	0.028	0.026-0.029
Total mined area for project (km^2)	31.5	12.9-14.3

SOURCES: (*a*) Syncrude Canada Ltd (1978): (*b*) Project Independence (1974).

toration techniques, temporary land disturbance could also be an advantage and, in some cases, the land may be of better quality after the operation than it was before.

MATERIALS

It is possible to identify three aspects which are closely related:

-- the nature of the raw material
-- the equipment
-- the wastes

Table III.3 shows certain characteristics of different raw materials. Because they contain rather low percentages of organic matter it is necessary to handle relatively large quantities of these raw materials. Both have in common a deficiency of hydrogen and significant quantities of impurities. In terms of the physical state of the organic matter of each material, tar sand seems to have some advantage because it contains oil as such.

Table III.3. Properties of tar sand and oil shale

	Tar sand	Oil shale
Organic matter (Wt%)	9-13.5	14-20
Inorganic matter (Wt%)	80-90	78-85
Moisture (Wt%)	2-10	1-2
Organic composition (Wt%)		
Carbon	83.1	79.81
Hydrogen	10.3	10.2-10.5
Oxygen	1.4	4.8-06.7
Nitrogen	0.3	2.1-02.6
Sulphur	4.9	0.9-01.2

SOURCE: Cameron (1969).

The stripping ratio and the ore grade affect the production considerably. Table III.4 shows, for example, that for tar sand, in one of the most favorable zones, about one ton of overburden must be removed and two tons of tar sand must be mined in order to produce one barrel of synthetic fuel.

In order to be economically viable the exploitation must be very large, which implies the use of "giant" equipment because of the economy of scale (see Table III.5). The heavy equipment represents a large amount of investment and the maintenance of this equipment is important since any stop in production involves a "heavy" loss in productivity. Therefore, the average performance of these machines is more important than their peak performance, and a high rate of usage is necessary for the economy of the processes.

Table III.6 gives information on another very serious problem, that of waste production. For example, mining of oil shale results in a volume of processed shale that is about 1.2 times greater than that of the raw shale. Because of this expanded volume, a complete return in the excavated area is impossible. One possible solution is to deposit the spent shale in deep natural canyons, which involves an additional cost for transportation and considerable impact on the scenic quality of the landscape. For tar sands, even if the nature of the waste is different, the question is also serious and the problem of storage area for tailings is becoming more acute.

MANPOWER

For all these processes, manpower requirements for construction and operation are very important. Table III.7 gives some figures relating to the Syncrude Plant (1978), to the Imperial Project (Resources Management Consultants Ltd. (1978), and some oil shale projects; Bechtel Corporation, 1976).

Table III.4. Materials mined to produce 1 barrel of synthetic fuel

Tar sand mining[a] open pit		Oil shale mining[b]	
Over-burden (t)	Tar sand (t)	Under-ground (t)	Open pit (t)
1	2-2.2	1.5	2

[a]Values for tar sand correspond to the conditions of the current GCOS and SYNCRUDE complexes--they are among the most favorable.

[b]Values correspond to very high-grade oil shale (35 g/st) and to classical retorting and upgrading processes.

Manpower problems represent one of the most serious potential bottlenecks in view of the big development in exploitation of this kind of resource. This is due to the following:

- -- Design and construction of tar sand or oil shale plants call upon the services of a very wide range of qualified workers (boiler makers, carpenters, cement finishers, electricians, insulators, iron workers, millwrights, plumbers and pipefitters, operating engineers and pressure welders) and require experience in widely different areas such as solid handling, mining and upgrading. Very few of the design and engineering companies can cope with this demand.
- -- Moreover, there are high peaks in the work force requirements. Unless a very tight schedule is established for the different projects there could be wide fluctuation in the employment market.

One of the main constraints on fast expansion will therefore be the relative scarcity of engineers and skilled workers. Even in the operational phase, the oil companies will have to face a new situation. Manpower requirements for the production of conventional oil (especially since the discovery of giant fields) have been low. For example, a field in North Alaska, with an output of 180,000 barrels per day requires only 23 man-years for operation and maintenance (Bechtel Corporation, 1975, 1976).

The influx of large numbers of workers into relatively remote or scarcely-populated areas (Colorado, for example) could have a significant social impact on the area and would require the construction of new schools, roads, hospitals, etc. This would also mean the consumption of water, land, energy, and materials for domestic use and it is therefore also necessary to take into account all these *indirect* WELMM requirements.

Table III.5. Main characteristics of syncrude and CGOS

	C G O S	SYNCRUDE
Site clearing commenced	1963	December 1973
On stream date	September 1967	August 1978
Daily production of synthetic crude oil	45 000	125 000
Total cost of project	$ 300 Million (1974)	$ 2500 Million
Average muskey depth	4 m	3 m
Average overburden	16 m	15 m
Average oil sand depth	40 m	42 m
Potential reserves	800 million bbl of bitumen	3500 million bbl of bitumen
Density of Bitumen	6 - 10° API	About 10° API
MINING	- Front end loaders number : 7 typical capacity : 11.5m^3 net power : 700 hp production of loading: 1210m^3/hr	- Draglines number: 4 60m^3 bucket 110 boom 104 working radius 13000 hp : power usage
	- Trucks number : 21 weight : 100 t pay load : 136 t engine power: 1600 hp	
	- Bucket wheel excavators number : 2 weight : 1600 t number of buckets: 10 average output : 3900 t/hr	
TRANSPORT	- Belt wagons number: 2 weight: 390 t	- Bucket wheel reclaimer number : 4 weight : 2250 t number of buckets: 14 capacity : 6400 t/hr
	- Conveyors length: 6 km width : 1.83 m	- Conveyors length: 8 km in mine 1.6 km in plant width : 2.10m
EXTRACTION PLANT	- 4 parallel processing lines capacity of each 1400t/hr	Processes 11800 t/hr
	- Rotating drum diameter: 5.19m length : 15.56 m	Rotating tumblers diameter: 5.4 m length : 30 m
UPGRADING	- Delayed coking drums number : 6 diameter: 7.9 m height : 29 m	Fluid cokers number: 2 height: 63 m
UTILITIES PLANT		Power plant 260 MW

Table III.6. Waste produced in the production of 1 barrel of synthetic fuel

Tar sand mining[a]			Oil shale mining[b]
Sand (t)	Water (t)	Bitumen	Spent shale (t)
1.8	1.9	0.03	1.2

[a]Values for tar sand correspond to the conditions of the current GCOS and SYNCRUDE complexes--they are among the most favorable.

[b]Values correspond to very high-grade oil shale (35 g/st) and to classical retorting and upgrading processes.

TABLE III.7. Manpower requirements for different synthetic liquid fuel processes

Projects	Design and Construction manpower requirements (man-hours)	Total workforce at peak construction	Workforce for operation and maintenance
Tar sand, SYNCRUDE, open-pit mining (125,000 bbl/d)[a]	43×10^6	7,500	2,500
Tar sand, in-situ process (141,000 bl/d), Imperial Project[b]	55×10^6	9,930	2,036
Oil shale, open-pit mining (100,000 bbl/d)[c]	8.7×10^6	2,200	1,800
Oil shale, underground mining (100,000 bbl/d)[c]	8.7×10^6	2,200	2,362

SOURCES: (*a*) Syncrude Canada Ltd. (1978); (*b*) Resources Management Consultants Ltd. (1978); (*c*) Project Independence (1974).

The above assessment of the WELMM requirements of different synthetic fuel processes clearly shows that the magnitude of means used will not be of the same order as for the recovery of conventional oil. We are truly entering the "Dinosaur era" of complex plants. On the other hand, the WELMM comparison between tar sand and oil shale does not show a big disadvantage to oil shale, although this would have been true if one had considered only their capital costs.

Again, the current techniques of exploitation of these resources are not utilizable for small deposits which could make useful contributions to the energy supply. It is therefore necessary to develop new methods, better adapted to the smaller deposits and to the human and material resources available--for example, less capital-intensive mining and smaller upgrading plants.

IV. THE UNCONVENTIONAL RESOURCE DATA BASE

As already emphasized in Part I, the information available on tar sand, heavy oil and oil shale is very poor. Barnea pointed out at the Edmonton Conference that figures relative to this type of resource are never published by organizations such as the American Petroleum Institute or by the Oil and Gas Journal. It is felt essential to make some effort towards filling the gap and cataloging all sources of information, putting special emphasis on automated data files containing information on individual deposits.

Because it is an international and a non-governmental institute and has the capacity to deal with many countries and organizations in the world, IIASA is in a good position to contribute to a better understanding of such resource bases. It was this necessity to improve data which was the initial incentive for designing the Unconventional Data Base.

DESCRIPTION OF THE DATA BASE

The Data Base consists of three separate files: Tar Sand, Heavy Oil and Oil Shale files. However, since these three files have the same structure only the Tar Sand File will be discussed here.

The file gives, country by country, the main tar sand deposits in the world, together with some of their characteristics. The data recorded for each deposit are grouped into four categories as follows:

1. Location and general information on deposit
2. Columnar section
3. Characteristics of reservoirs
4. Characteristics of bitumen

Difficulties arose in defining the number and the values of parameters for each category. Some deposits, such as the Athabasca deposit, are very well known and well documented and in this case it is possible to store thousands of data values. However, this is really an exception and for most world deposits there is only estimated data; which is why the choice of parameters is a compromise and only the main characteristics have been selected. Nevertheless, they are assumed sufficient to identify and classify the deposit. Example 1 of the Appendix shows a complete list of the parameters. The other difficulty lies in choosing the values to be given to the quantitative data. Obviously, thickness or porosity vary over the entire deposit. Therefore, minimum, maximum and average values are given for all parameters.

The Storage and Retrieval System

It is important to consider the following points when storing files on the computer:

- -- the speed and ease of accessing data in a clear language (storage, retrieval and corrections);
- -- the possibility of making use of the computer for selecting comparisons of parameters.

We used a data base management system with a "quasi natural language". This system, called the INGRES System, was created at the University of Berkeley and can be run on a PDP computer. By using the command "tarsand show" followed by the code number for the deposit, we are able to access all the data relative to the deposit (see Example 2). However, the main function of the Data Base is not limited to documentation or to a simple retrieval of inputs. By using Ingres it is possible to make various operations of reclassification or to relate parameters in order to consider whether correlations exist between these parameters (see Examples 3,4 and 5).

Example 1. List of parameters

I LOCATION AND GENERAL INFORMATION OF DEPOSIT

	Relation	Attribute Name
CODE	tara	code
COUNTRY		country
STATE		state
REGION		region
BASIN		basin
DEPOSIT FIELD NAME		depfldnam
YEAR OF DATA REFERENCE (YEAR)		discdate
SURF EXTENSION (KM**2)	tarb	surfext
MINIMUM PAY THICKNESS - MINING (M)		minpaythkmn
MAXIMUM PAY THICKNESS - MINING (M)		maxpaythkmn
AVERAGE PAY THICKNESS - MINING (M)		avgpaythkmn
MINIMUM PAY THICKNESS - INSITU (M)		minpaythkins
MAXIMUM PAY THICKNESS - INSITU (M)		maxpaythkins
AVERAGE PAY THICKNESS - INSITU (M)		avgpaythkins
DEPTHS OF RESERVOIR MINIMUM (M)		mindepres
DEPTHS OF RESERVOIR MAXIMUM (M)		maxdepres
DEPTHS OF RESERVOIR AVERAGE (M)		avgdepres
OVERBURDEN THICKNESS MINIMUM (M)	tarc	minoverbthk
OVERBURDEN THICKNESS MAXIMUM (M)		maxoverbthk
OVERBURDEN THICKNESS AVERAGE (M)		avgoverbthk
BITUMEN IN PLACE MINING MINIMUM (MILL BBL)		minbitplcmin
BITUMEN IN PLACE MINING MAXIMUM (MILL BBL)		maxbitplcmin
BITUMEN IN PLACE MINING AVERAGE (MILL BBL)		avgbitplcmin
BITUMEN IN PLACE INSITU MINIMUM (MILL BBL)		minbitplcins
BITUMEN IN PLACE INSITU MAXIMUM (MILL BBL)		maxbitplcins
BITUMEN IN PLACE INSITU AVERAGE (MILL BBL)		avgbitplcins
BITUMEN IN PLACE TOTAL MINIMUM (MILL BBL)		minbitplc
BITUMEN IN PLACE TOTAL MAXIMUM (MILL BBL)		maxbitplc
BITUMEN IN PLACE TOTAL AVERAGE (MILL BBL)		avgbitplc.
ANTICIPATED SURF RECOVERY MINING MINIMUM (%)	tard	minansuremin
ANTICIPATED SURF RECOVERY MINING MAXIMUM (%)		maxansuremin
ANTICIPATED SURF RECOVERY MINING AVERAGE (%)		avgansuremin
ANTICIPATED SURF RECOVERY INSITU MINIMUM (%)		minansureins
ANTICIPATED SURF RECOVERY INSITU MAXIMUM (%)		maxansureins
ANTICIPATED SURF RECOVERY INSITU AVERAGE (%)		avgansureins
ANTICIPATED SURF RECOVERY TOTAL MINIMUM (%)		minansuretot
ANTICIPATED SURF RECOVERY TOTAL MAXIMUM (%)		maxansuretot
ANTICIPATED SURF RECOVERY TOTAL AVERAGE (%)		avgansuretot
RECOVERABLE OIL MINING MINIMUM (MILL BBL)		minrecoilmin
RECOVERABLE OIL MINING MAXIMUM (MILL BBL)		maxrecoilmin
RECOVERABLE OIL MINING AVERAGE (MILL BBL)		avgrecoilmin
RECOVERABLE OIL INSITU MINIMUM (MILL BBL)	tare	minrecoilins
RECOVERABLE OIL INSITU MAXIMUM (MILL BBL)		maxrecoilins
RECOVERABLE OIL INSITU AVERAGE (MILL BBL)		avgrecoilins
RECOVERABLE OIL TOTAL MINIMUM (MILL BBL)		minrecoiltot
RECOVERABLE OIL TOTAL MAXIMUM (MILL BBL)		maxrecoiltot
RECOVERABLE OIL TOTAL AVERAGE (MILL BBL)		avgrecoiltot
RECOVERABLE UPGRADED OIL MINING MINIMUM (MILL BBL)		minrcupoilmn
RECOVERABLE UPGRADED OIL MINING MAXIMUM (MILL BBL)		maxrcupoilmn
RECOVERABLE UPGRADED OIL MINING AVERAGE (MILL BBL)		avgrcupoilmn
RECOVERABLE UPGRADED OIL INSITU MINIMUM (MILL BBL)		minrcupoilin
RECOVERABLE UPGRADED OIL INSITU MAXIMUM (MILL BBL)		maxrcupoilin
RECOVERABLE UPGRADED OIL INSITU AVERAGE (MILL BBL)		avgrcupoilin
RECOVERABLE UPGRADED OIL TOTAL MINIMUM (MILL BBL)	tarf	minrcupoilto
RECOVERABLE UPGRADED OIL TOTAL MAXIMUM (MILL BBL)		maxrcupoilto
RECOVERABLE UPGRADED OIL TOTAL AVERAGE (MILL BBL)		avgrcupoilto
POSSIBLE OTHER MINERAL DEPOSITS	targ	mindep

II COLUMNAR SECTION

	Relation	Attribute Name
NAME OF AGE	tarh	agename
NATURE OF SOIL TYPE		natsoiltyp
FORMATION NAME		formname

III CHARACTERISTICS OF RESERVOIRS

AGE	tari	age
TYPE		type
MINIMUM POROSITY (%)		minpor
MAXIMUM POROSITY (%)		maxpor
AVERAGE POROSITY (%)		avgpor
MINIMUM ABSOLUTE PERMEABILITY (md)		minabsperm
MAXIMUM ABSOLUTE PERMEABILITY (md)		maxabsperm
AVERAGE ABSOLUTE PERMEABILITY (md)		avgabsperm
MINIMUM EFFECTIVE GAS PERMEABILITY (md)	tarj	minefgasperm
MAXIMUM EFFECTIVE GAS PERMEABILITY (md)		maxefgasperm
AVERAGE EFFECTIVE GAS PERMEABILITY (md)		avgefgasperm
MINIMUM OIL SATURATION (% WEIGHT)		minoilsatwgt
MAXIMUM OIL SATURATION (% WEIGHT)		maxoilsatwgt
AVERAGE OIL SATURATION (% WEIGHT)		avgoilsatwgt
MINIMUM OIL SATURATION (% VOLUME)		minoilsatvol
MAXIMUM OIL SATURATION (% VOLUME)		maxoilsatvol
AVERAGE OIL SATURATION (% VOLUME)		avgoilsatvol
MINIMUM WATER SATURATION (% WEIGHT)	tark	minwatsatwgt
MAXIMUM WATER SATURATION (% WEIGHT)		maxwatsatwgt
AVERAGE WATER SATURATION (% WEIGHT)		avgwatsatwgt
SEDIMENTARY ENVIRONMENT		sedenv
TYPES OF TRAPS		typetrap
AGE OF SOURCE BEDS		agesrcbed
TIME OF MAIN GENERATION AND MIGRATION		timgenmig
MIGRATION DISTANCES (km)		timgenmig
MINIMUM RESERVOIR TEMPERATURE (deg C)		minrestemp
MAXIMUM RESERVOIR TEMPERATURE (deg C)		maxrestemp
AVERAGE RESERVOIR TEMPERATURE (deg C)		avgrestemp
MINIMUM RESERVOIR PRESSURE (psig)		minrespre
MAXIMUM RESERVOIR PRESSURE (psig)		maxrespre
AVERAGE RESERVOIR PRESSURE (psig)		avgrespre
BASINAL SETTING		basinset

IV CHARACTERISTICS OF BITUMEN

	Relation	Attribute Name
DEGREE API GRAVITY MINIMUM	tarl	mindegapigrv
DEGREE API GRAVITY MAXIMUM		maxdegapigrv
DEGREE API GRAVITY AVERAGE		avgdegapigrv
VISCOSITY MINIMUM (cps)		minvisc
VISCOSITY MAXIMUM (cps)		maxvisc
VISCOSITY AVERAGE (cps)		avgvisc
BOILING RANGE MINIMUM		minboilrng
BOILING RANGE MAXIMUM		maxboilrng
BOILING RANGE AVERAGE		avgboilrng
POUR POINT MINIMUM (degree celcius)		minpourpt
POUR POINT MAXIMUM (degree celcius)		maxpourpt
POUR POINT AVERAGE (degree celcius)		avgpourpt
C MINIMUM (% weight)	tarm	minc
C MAXIMUM (% weight)		maxc
C AVERAGE (% weight)		avgc
S (% WEIGHT) MINIMUM		mins
S (% WEIGHT) MAXIMUM		maxs
S (% WEIGHT) AVERAGE		avgs
N (% WEIGHT) MINIMUM		minn
N (% WEIGHT) MAXIMUM		maxn
N (% WEIGHT) AVERAGE		avgn
O MINIMUM (% weight)		mino
O MAXIMUM (% weight)		maxo
O AVERAGE (% weight)		avgo
ASPHATENES (%)	tarn	asphatenes
COLOR		color
HEAVY METALS	taro	heavymetal

Example 2. Data available for Cold Lake Deposit

CODE	0002ab

I LOCATION AND GENERAL INFORMATION OF DEPOSIT: cold lake

COUNTRY	canada
STATE	alberta
REGION	eastern alberta
BASIN	manville group
DEPOSIT FIELD NAME	cold lake
YEAR OF DATA REFERENCE (YEAR)	1976
SURF EXTENSION (KM**2)	9065
MINIMUM PAY THICKNESS - INSITU (M)	5
MAXIMUM PAY THICKNESS - INSITU (M)	16
DEPTHS OF RESERVOIR AVERAGE (M)	457
OVERBURDEN THICKNESS AVERAGE (M)	457
BITUMEN IN PLACE INSITU AVERAGE (MILL BBL)	270000
BITUMEN IN PLACE TOTAL AVERAGE (MILL BBL)	270000
ANTICIPATED SURF RECOVERY INSITU MINIMUM (%)	12
ANTICIPATED SURF RECOVERY INSITU MAXIMUM (%)	25
ANTICIPATED SURF RECOVERY TOTAL MINIMUM (%)	12
ANTICIPATED SURF RECOVERY TOTAL MAXIMUM (%)	25
RECOVERABLE OIL INSITU MINIMUM (MILL BBL)	20000
RECOVERABLE OIL INSITU MAXIMUM (MILL BBL)	40000
RECOVERABLE OIL TOTAL MINIMUM (MILL BBL)	20000
RECOVERABLE OIL TOTAL MAXIMUM (MILL BBL)	40000
RECOVERABLE UPGRADED OIL INSITU MINIMUM (MILL BBL)	15000
RECOVERABLE UPGRADED OIL INSITU MAXIMUM (MILL BBL)	30000
RECOVERABLE UPGRADED OIL TOTAL MINIMUM (MILL BBL)	15000
RECOVERABLE UPGRADED OIL TOTAL MAXIMUM (MILL BBL)	30000

II COLUMNAR SECTION

AGE	NATURE OF SOIL	FORMATION NAME
cretaceous	: marine shale	: lower colorado
devonian	: --unknown--	: woodbend,beaverhill lake
lower cretaceous	: marine sandstone,glauconite	: clearwater
lower cretaceous	: nonmarine quartz sandstone	: mcmurray
lower cretaceous	: nonmarine sandstone	: lower grd rapid member
lower cretaceous	: nonmarine sandstone	: upper grd rapid member

III CHARACTERISTICS OF RESERVOIRS

AGE	early cretaceous
TYPE	sand
MINIMUM POROSITY (%)	28
MAXIMUM POROSITY (%)	35
MINIMUM ABSOLUTE PERMEABILITY (md)	350
MAXIMUM ABSOLUTE PERMEABILITY (md)	1300
MINIMUM OIL SATURATION (% WEIGHT)	4
MAXIMUM OIL SATURATION (% WEIGHT)	12
AVERAGE OIL SATURATION (% WEIGHT)	8
MINIMUM OIL SATURATION (% VOLUME)	8
MAXIMUM OIL SATURATION (% VOLUME)	23
MINIMUM EFFECTIVE GAS PERMEABILITY (md)	50
MAXIMUM EFFECTIVE GAS PERMEABILITY (md)	500
MINIMUM OIL SATURATION (% WEIGHT)	2
MAXIMUM OIL SATURATION (% WEIGHT)	20
SEDIMENTARY ENVIRONMENT	deltaic
TYPES OF TRAPS	structural-stratigra
AGE OF SOURCE BEDS	mesozoic
TIME OF MAIN GENERATION AND MIGRATION	upper mesozoic
BASINAL SETTING	coastal zone
SEDIMENTARY ENVIRONMENT	deltaic
TYPES OF TRAPS	structural stratigra
AGE OF SOURCE BEDS	early cretaceous
TIME OF MAIN GENERATION AND MIGRATION	late cretaceous
MIGRATION DISTANCES (km)	135
AVERAGE RESERVOIR TEMPERATURE (deg C)	12
AVERAGE RESERVOIR PRESSURE (psig)	440
BASINAL SETTING	foreland

IV CHARACTERISTICS OF BITUMEN

DEGREE API GRAVITY MINIMUM	10
DEGREE API GRAVITY MAXIMUM	14
VISCOSITY AVERAGE (cps)	100000
S (% WEIGHT) AVERAGE	4.700
N (% WEIGHT) AVERAGE	0.200
O AVERAGE (% weight)	0.900
ASPHATENES (%)	15.000
HEAVY METALS	nickel70ppm
HEAVY METALS	vanadium 240ppm

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3- j Starr,J.M Prats:Chemical Properties and Reservoir Characteristics of bitumen and Heavy Oil from canada and venezuela.First international conference on Heavy crude and Tar sands.Edmonton june1979
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Example 3. List of all tar sand deposits

```
range of a is tara
retrieve (a.code,a.country,a.depfldnam)

Icode  Icountry                    Idepfldnam                    I
I-------------------------------------------------------------I
I0001abIcanada                     Iathabasca                    I
I0001adIusa                        Iasphalt ridge                I
I0001bbItrinidad                   Itrinidad asphalt lakI
I0001diIvenezuela                  Iguanoco-pitch lake           I
I0001fhIrumania                    Iderna                        I
I0001fbIalbania                    Iselenizza                    I
I0001fiIurss                       I--unknown--                  I
I0001hxImalagasy rep               Ibemolanga                    I
I0002abIcanada                     Icold lake                    I
I0002adIusa                        Isunnyside                    I
I0002diIvenezuela                  Iorinoco oil belt             I
I0002fiIurss                       I--unknown--                  I
I0003abIcanada                     Ipeace river                  I
I0003adIusa                        Ihill creek                   I
I0003fiIussr                       Iin timano pechorskoyI
I0004abIcanada                     Iwabasca                      I
I0004adIusa                        Ip.r spring                   I
I0004fiIussr                       Isiligir                      I
I0005abIcanada                     Imelville island              I
I0005adIusa                        Icircle cliffs                I
I0005fiIussr                       Iolenekskoe                   I
I0006adIusa                        Itar triangle                 I
I0006fiIurss                       Imelekess                     I
I0007adIusa                        Iedna                         I
I0007fiIurss                       Icheildag                     I
I0008adIusa                        Isisquoc                      I
I0009adIusa                        Isanta cruz                   I
I0010adIusa                        Idavid dismal creek           I
I0011adIusa                        Iasphalt                      I
I0012adIusa                        Ikyrock                       I
I0013adIusa                        Isanta rosa                   I
I0014adIusa                        Isan rafael swell             I
I0015adIusa                        Iraven ridge                  I
I0016adIusa                        Iargyle canyon                I
I0017adIusa                        Iasphalt ridge                I
I0018adIusa                        Iwhiterocks                   I
I0019adIusa                        Ijacks canyon                 I
I0020adIusa                        Iwickiup                      I
I0021adIusa                        Imaud                         I
I0022adIusa                        Irimrock                      I
I0023adIusa                        Iwillow creek                 I
I0024adIusa                        Ipariette                     I
I0025adIusa                        Iwhite canion                 I
I0026adIusa                        Ilittlewater hill             I
I0027adIusa                        Ilake fork                    I
I0028adIusa                        Inine mile canyon             I
I0029adIusa                        Ichapita wells                I
I0030adIusa                        Iten mile wash                I
I0031adIusa                        Itabiona                      I
I0032adIusa                        Ithistle                      I
I0033adIusa                        Ispring branch                I
I0034adIusa                        Icow wash                     I
I-------------------------------------------------------------I
```

Example 4. Selection of deposits in a given country

```
retrieve (a.all) where a.country = "canada"
```

code	country	state	region	basin	depfldnam	discda
0001ab	canada	alberta	northern alberta	mcmurray formation	athabasca	1976
0002ab	canada	alberta	eastern alberta	manville group	cold lake	1976
0003ab	canada	alberta	western alberta	bluesky gething form	peace river	1976
0004ab	canada	alberta	north central albert	grd rapid clearwater	wabasca	1976
0005ab	canada	--unknown--	canadian artic	sverdrup	melville island	1963

Example 5. List of deposits with estimated resources greater than 10^9 bbl (one unit is 10^6 barrels).

```
range of a is tara
range of b is tarc
retrieve (a.code,a.depfldnam,b.minbitplo,b.avgbitplc,b.maxbitplo)
where b.minbitplo >  1000
or    b.avgbitplc >  1000
and       a.code  =  b.code
```

bial relation

code	depfldnam	minbitplo	avgbitplc	maxbitplc
0001ab	athabasca	-1	869000	-1
0001bb	trinidad asphalt lak	-1	2000	-1
0001hx	bemolanga	-1	22000	-1
0002ab	cold lake	-1	270000	-1
0002ad	sunnyside	3500	-1	4000
0003ab	peace river	-1	92000	-1
0003ad	hill creek	-1	1160	-1
0004ab	wabasca	-1	119000	-1
0004ad	p.r spring	4000	-1	4500
0004fi	siligir	-1	12000	-1
0005fi	olenekskoe	-1	7000	15000
0006ad	tar triangle	12500	-1	16000
0006fi	melekess	-1	122000	-1

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