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The Utilization of Tasmanian Oil Shale

November 12, 1984

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Hobart

Report to Endeavour Resources Limited on the Utilization of
Tasmanian Oil Shale.

by R.F. Cane

Summary. During the tenure of a professorship at the University of Utah, and on behalf of Endeavour Resources, the writer had discussions with organizations in the U.S. involved in the development of oil shale as an energy source.

The present U.S. liquid fuel situation is an embarrassing surplus of petroleum stocks, decreasing cost of crude oil and a low retail price for gasoline, hence there is little industrial interest in alternative fuel liquids. The government view is that the U.S. has sufficient access to petroleum "to see them well into the next century".

Nevertheless a small section of informed opinion feels strongly that it is unwise to discontinue investigating non-petroleum fuels in case the international situation quickly changed and deteriorated.

Overall there has been a drastic curtailment of work on synfuels i.e. oil from coal, shale and tar sands. Outside of academic research and, with few exceptions, there is a growing disinclination to spend further money in this field, particularly as plant capital costs have more than doubled in the last few years. More specifically with regard to tasmanite, because of the nature of the oil, the smallness and isolation of the deposit, and the cost of transport to market, no support was received for the concept of the commercial production of shale oil; a view which is supported by this writer. It is believed that no case can be made out for any large scale thermal conservation of the kerogen, i.e. there is no economic inducement for the production of shale oil, bitumen or other pyrolysis product.

There was support for the use of powdered enriched tasmanite as fuel, either mixed with oil and fed to boilers, or mixed with coal and used as solid fuel.

Experts thought it unlikely that a useful outlet could be found for kerogen as a chemical raw material but a use might be found for the concentrate in other ways, such as a soil conditioner or as an organic diluent for industry.

Recommendations. It is recommended that:

1. Using existing information, a rough estimate be made of the production cost of a tasmanite concentrate containing about 75% organic matter. It is suggested that the estimate be based on an annual production rate of 50,000 tonnes of concentrate, equivalent to about 172,000 tonnes of raw shale.
2. If the cost of the tasmanite concentrate obtained from Recommendation (1), including delivery to Goliath Cement at Railton and/or to the H.E.C. power station at Bell Bay, be competitive with delivered oil (Bell Bay) or Fingal coal (Railton), then a more detailed estimate be made. It is possible that this further estimate may need some background experimental data such as shale grindability (Bond Index), efficiency of flotation concentration (there may be sufficient data in the Tasmanian Mines Dept. reports), selective chemical analyses, and evaluation of dust hazards, etc.
3. A small investigation be undertaken into the chemical modification of tasmanite concentrate to make it suitable as a soil conditioner. The concentrate presently available from the Tas. Mines Dept. would be suitable for this work.
4. Discussions be held with interested parties on the possible use of tasmanite concentrate as an organic diluent. Useful organisations might include CSIRO (Applied Chemistry), Olympic Rubber, I.C.I. (Australia), A.C.I. and similar bodies.
5. The Australian Coal Industry Research Laboratories be approached to see whether they would evaluate the effect of adding tasmanite concentrate to powdered coal in their coal liquids experiments.
6. Discussions be held with the Chairman of the Tasmanian Development Authority (Mr. Neil Ashdown) acquainting him with some of the thinking of this report and its recommendations. The Chairman has said that the Authority would favorably view any attempt to increase employment in the Latrobe area and that some financial assistance might be available for the early development work. Money should be sought for an exploratory investigation (including market evaluation) into the use of tasmanite concentrate as a soil conditioner and as an industrial organic diluent.

Conclusions. As a result of discussions in the U.S. and Australia during the period June-November 1984, the writer has made a preliminary appraisal of the commercial possibilities of Tasmanian oil shale (tasmanite) for the following uses:

1. Production of shale oil for refinery and other use.
2. Production of oil shale for fuel use, as mined and crushed.
3. Production of oil shale for chemical use.
4. Production of a tasmanite concentrate for fuel use.
5. Production of a tasmanite concentrate for miscellaneous uses.

It is concluded that :

1. Within the foreseeable future there is no commercial justification for the production of shale oil.
2. Mined and crushed tasmanite is not an attractive saleable product.
3. There is no encouragement for the production of marketable chemicals or intermediates from tasmanite. This is not to say that chemicals cannot be produced but existing knowledge does not lend hope to such a venture. Whether tasmanite can be made to yield useful chemical intermediates is a matter for extensive research, but the prospect does not look promising.
4. Tasmanite concentrate has a good potential market for fuel use provided the cost is competitive. The concentrate has use mixed with either coal or oil. The sale of such a concentrate depends on price and chemical analysis.
5. Tasmanite concentrate has possibilities for miscellaneous uses such as a soil conditioner or as an organic diluent.

THE UTILIZATION OF TASMANIAN OIL SHALEINTRODUCTION

The significant parts of Dr. Cane's Report are reproduced below. The information contained is based on Dr. Cane's recent visit to the United States, where on behalf of Endeavour Resources Limited a preliminary appraisal & research into the possible economic utilization of tasmanite (Tasmanian Oil Shale) either as an energy source or for other uses, was conducted.

The investigations included visits to oil shale experts & organizations for technical discussions & information exchange. (See List given in Appendix 1.).

Experts in the oil shale field were chosen as those likely to provide useful technological information rather than scientific data as it was considered that there is ample academic knowledge available from previous CSIRO & CRA reports & from published papers in the scientific press.

The report is divided into two sections :-

Section 1. The main report containing recommendations & conclusions.

Section 2. The subsidiary report on individual discussions where these do not contribute substantially to the aim of Section 1..

SECTION 1.The Liquid Fuel Position in the U.S.A. (1984)

Since 1981 in the U.S. there has been a complete reversal in outlook with regard to liquid fuels, both petroleum-derived and synfuels (oil from coal or oil shale). As a result of energy conservation, a switch to smaller cars and a buyers market for crude oil, the present situation is that petroleum is abundant, refineries are not at capacity and, in the U.S., gasoline price "at the pump" has slumped to what it was five years ago - a decrease of 24¢/gal in the last 18 months.

Even with refineries in "moth-balls" there is only sufficient fuel demand to give a 72% load to those refineries which are working. It has been said that the U.S. has enough installed refinery capacity so that there is no need for new ones for the next thirty years and existing storage problems are an embarrassment to refinery managers. Indeed, the "New York Times" has reported questions in Congress as to whether the

U.S. should not sell some of its underground strategic stockpile of crude oil as a means of stabilizing the position on imports.

The "famine-to-glut" situation has brought some interesting changes. There is now industrial pressure for larger cars, and no doubt, the oil industry will not actively discourage EPA in its endeavours to stop the use of lead in gasoline. Non-leaded gasoline will increase the demand for oil, as lead-free gasoline requires more hydrocarbons per mile than leaded gasoline.

Synthetic Fuels

The position on synfuels can only be described as chaotic. As late as November 1981, the U.S. technical press were projecting important corporate decisions on commitments for future synfuels projects involving government and industrial expenditure of more than thirty billion dollars. Thirty months later some members of the House of Representatives, critical of the synfuels program, were advocating a complete withdrawal of all funding from the U.S. government's Synthetic Fuels Corporation and four of the five directors have resigned. Four years ago, the U.S. government synfuel's program had a budget of \$20 billion to turn national resources, such as coal, oil shale and tar sands into useful fuel. The U.S. Congress recently voted to withdraw \$5000 million from the unspent funds leaving only \$8 billion to complete existing projects.

With regard to the shale oil programs, one trouble is the massive increase in the cost of erected plant. This situation is exemplified by the decision of Exxon to shut down the Colony Oil Shale (Colorado) project. In 1980/81 the estimated cost of the Colony Oil Shale project was \$3400 million. By 1982/83 the basic facilities for a new town had been completed, including the streets and amenities. Within the two years projected completion costs had risen to \$5200 million.

At that stage Exxon, which had spent \$400 million on the site development, decided to terminate the project and shut up the town. Exxon had to pay a partner a further \$380 million as part of the contract, on closure of the program. The Rio Blanco and the Cathedral Bluff projects are at a standstill and, in August this year, the U.S. government decided to withdraw \$5 million of support from the Parachute Creek scheme.

Somewhat unaffected by the near collapse of industrial activity on oil shale, research work in universities and technical institutions is active, perhaps in the hope that the position could reverse itself once again; outside a major war, this is believed unlikely. It appears that some academic activity in oil shale is focussed on the hope that further investigations will reveal new technologies which will be less capital intensive, or demand less mining costs or provide a cheaper and better shale oil.

Present Situation on Oil Shale Mining and Beneficiation

For more than twenty years there has been great emphasis on an old idea in which oil shale is heated without removal from the ground. The in-situ retorting process envisages heating the oil shale in place, whereupon the oil flows away and the carbonaceous shale residue is allowed to burn as a source of heat. Many "old hands" (including R.F.C.) maintained that the process wouldn't work because of lack of heat transfer and because of channelling of the flame front. After the expenditure of about \$420 million on research, pilot investigations and some full-scale trials, the process is near moribund because of, as yet, insurmountable technical difficulties. Apart from some experiments by Geokinetics, technical thinking has returned to above-ground retorting.

Because about half the production cost of shale oil (ex mining) is in materials' handling, there is now activity into means of removing the mineral matter from oil shale, prior to its being retorted, i.e. oil shale (kerogen) beneficiation. There has been a second influence giving rise to interest in oil shale beneficiation processes. This recent change in emphasis has been caused by the realization that, for an equal ash (mineral matter) content, oil shale may be a cheaper source of satisfactory synthetic liquid fuel than coal. This altered thinking has come about because of the increased cost of hydrogen. Bituminous coal contains about 5% hydrogen whereas oil shale kerogen contains between 11% and 12.7% hydrogen. Hence the hydrogen demand for the total conversion of kerogen to fuel liquids is about half that for coal conversion processes. Thus there is a growing realization that, if oil shale could be reduced in ash (beneficiated) to an amount similar to that in coal, the enriched product might be amenable to coal liquification processes and easier to handle. Hence, if a synfuels program were ever necessary in the future, oil shale might be a better starting material.

The above factors have influenced research organizations to examine the following topics:

1. Can oil shale be upgraded to a kerogen rich product?
2. What decreased capital and energy savings might accrue by processing a kerogen concentrate?
3. What are the capital and process costs of beneficiation?
4. Suitable methods of oil production from the kerogen concentrate.
5. The nature of the oil produced from a kerogen concentrate.

The U.S. Department of Energy commissioned a research program on the beneficiation of oil shale and a report entitled "The Technical and Economic Feasibility of Oil Shale Beneficiation by Heavy Media" has been prepared. This report, of nearly 300 pages including costing and additional information, is being held by the writer pending a decision as to whom to send it.

The Department of Energy sees the beneficiation technique as a favorable way of overcoming the inherent disadvantages of oil shale. However, for Green River shale, it has been found that grinding down to 20μ has to be achieved before effective separation can be obtained. This operation is very costly and difficult. However, neglecting costs, fine grinding and froth floating does produce a suitable concentrate.

The U.S. Department of Energy showed considerable scepticism for the need to spend further money on synthetic fuels. Indeed they stated that the EPA is examining the environmental impact information on grinding and extracting oil shales. They said that, if the EPA reports are unsatisfactory "the DOE may drop the whole program".

The intractability of the Green River oil shale to comminution and beneficiation has caused a shift in interest to the eastern Devonian shales as possible source materials. Both wet and dry concentration processes have been evaluated. Results to date have demonstrated that froth flotation is nearly twice as efficient as any other known technique. Unfortunately wet concentration introduces a drying step in the process chain.

With regard to beneficiation: tasmanite is unique. It is this feature and this feature alone which provides any promise for the commercial utilization of tasmanite. Tasmanite kerogen is the remains of a spherical alga and the organic matter is discrete, of large particle size (200-500 μ), and the kerogen is easily separated. Approximately ten years ago the Laboratories of the Tasmanian Department of Mines carried out tests on the concentration of tasmanite by flotation. These tests were made on behalf of Endeavour Oil NL and one may assume that the results are available to Endeavour Resources (Tas. Mines Dept. Technical Report 20 (1975) - R693 & R694). The following reports on this topic have been brought back from the U.S.:

1. "New Ways to process Oil Shale" Chemical Engineering, February 1982.
2. "Concentration of Oil Shale" Mineral Processing & Technology Review 1, 207 (1983).
3. "Cyclone whips up better Shale" Chem. Engineering, November 1981.
4. "Concentration of Eastern Oil Shale by Froth Flotation" Proc. 1982 Shale Symposium.
5. "Oil Shale Beneficiation for above ground Retorting" Mining Engineering, September 1982.
6. "Technical and Economic Feasibility of Oil Shale Beneficiation by Heavy Media" Fuels & Mineral Resources, 1984, DOE Contract DE-ACOL-80ET-14364.

The Use of Tasmanite Concentrate as Fuel

The use of raw oil shale for steam and power generation has been practiced by the U.S.S.R. (Estonia) for nearly half a century. Although the statistics of shale production are unavailable, it is believed that nearly 40 million tons of shale are mined annually for fuel; very little being converted to oil and that only for petrochemicals manufacture. The raw shale is fired directly under boilers, 60% of all Estonian oil shale (kukkersite) is burned for power generation while some is used for locomotion (railways).

It is obvious that Tasmanian conditions - economic, technical and social - would not be conducive to the direct firing of power house boilers with raw tasmanite, but the use of tasmanite concentrate might

bear further consideration. In discussion with Goliath Cement it was clear that Works Management was sympathetic to the proposal, provided the cost was attractive. The use of tasmanite, perhaps blended with coal, at Railton has the added advantage that the ash should find a ready use in their cement manufacture. The ash which is high in silica and alumina should be an excellent additive to the raw cement mix before burning.

The Hydro Electric Commission considered the use of tasmanite concentrate mixed into the fuel oil at the Bell Bay power station but points out that the mineral matter could be unduly abrasive to the burner nozzles. The H.E.C. also stated that the oil pumps to the burners operate on very close tolerances, hence the shale powder would need a separate injector system after the oil pumps. Nevertheless, in principle, they are willing to consider the suggestion. However, a series of small scale trials would have to be carried out (perhaps at the University) before they would be willing for a test at the Bell Bay station. The H.E.C. also point out that there are many small boiler installations on the Tasmanian north coast which would be more suitable for burning a concentrate powder blend.

Tasmanite Concentrate in Horticulture

The provision of chemicals to improve the fertility of soils is an old but expanding industry. The addition of special fertilizers, trace metals and plant hormones has now become well established. More recently, speciality chemicals, modified natural products and polymers are added to soils to increase water retention, porosity and other properties. In some ways the last mentioned type act like compost or leaf mulch but in a more specific manner.

Soil conditioners find a ready market in Australia where plant nurseries have a billion dollar industry. One nursery in Tasmania has an annual turnover in the multimillion dollar range.

Nurseries and horticultural areas use peat, special brown coal or modified (sulphonated) black coal amongst other substances to "condition" their soils. These additives are hydrophilic and often act as ion exchangers. It is conjectured that chemical modification of tasmanite kerogen to increase its hydrophilic character might well produce a good soil conditioner.

Other speciality uses might be in the rubber industry where the sulphur and ether linkages in the kerogen molecule might exhibit useful properties. These and other applications can only be found by trial-and-error.

Hydrogenation

There is some "high flying" experimentation on oil shale pyrolysis using hydrogenation techniques. The foremost of these is the endeavours of the Institute of Gas Technology (Chicago) with the Hytort process. I.G.T. through an associate, the Hycrude Corporation, expressed interest in testing tasmanite and samples have been submitted to them. During discussions with I.G.T. it became obvious that the process is very capital intensive, demands high throughputs and is unlikely to be of interest because of the lack of natural gas for hydrogen production. Further I.G.T. admit that the Hytort process does not give much improvement for shales richer than 25 gpt. The process is designed for low grade oil shales. Nevertheless I.G.T. undertook to evaluate tasmanite in the Hytort process and send the results to Australia.

In addition to the I.G.T., the Colorado School of Mines is experimenting with the direct hydrogenation of oil shale under autoclave conditions - the hydrothermal extraction process. The advantages of hydrothermal extraction, rather than "dry" retorting for the production of shale oil is that, as cracking conditions are relatively gentle, the decomposition gives a better carbon conversion (85% compared to 65% max. with retorting), and a greater selectivity to oil (90%). Additionally the product oil contains less condensed aromatic structures (about half) and considerably less olefins (about one quarter). In other words, the shale oil from thermal extraction rather than retorting has a much better "chemistry", it shows less coking and is a better feed for up-grading for use as a petroleum feed-stock. The disadvantages are that hydrothermal extraction is a pressure process with high cost capital equipment and, second, it requires a copious hydrogen supply which is expensive and demands natural gas or equivalent.

The Colorado School of Mines was anxious to evaluate their hydrothermal extraction process on the tasmanite concentrate and samples were given to them.

The following publications are held:

"Selection of a Commercial Plant Design for the Hytort Process"

"Experimental Test Program of the Hytort Feasibility Study"

"Hydroprocessing of Stuart Oil Shale"

"Solvent Refining of Oil Shale"

SECTION II

Discussions with the Western Research Institute

The Western Research Institute (WRI) is the new organization of the former Laramie Laboratories of the U.S. Department of Energy. WRI, and its predecessors (L.E.T.C. and the former Bureau of Mines Laboratories), have been active in oil shale investigations since before World War II. When WRI was the Laramie Energy Technology Center it was the U.S. government centre for oil shale technology and, together with the Livermore Laboratories of the University of California (now one of the National Research Institutes) has carried out the major portion of oil shale investigations in the western world.

Since the severe curtailment of synfuel work within DOE and the "splitting off" of L.E.T.C. into the WRI, the scope of oil shale research at Laramie has contracted, indeed, they have funds for less than two years into the future and many of their senior people have found jobs elsewhere.

The people at Laramie were very disillusioned about the future of shale oil, as seen from the present. They said that the "breathing space" provided by the present excess petroleum situation will enable alternatives, other than shale oil and oil-from-coal, to be brought to fruition. Mention was made of synthetic gasoline via the Mobil process and further substitution of hydrocarbons by other energy sources; thus releasing more crude oil. They also said the energy future is becoming more and more confused worldwide.

Scientists at WRI undertook to examine the sample of tasmánite concentrate and report whether it possessed any abnormal chemical properties which would merit special investigation.

Discussions with the Institute of Gas Technology

Since 1972 the Institute of Gas Technology has been concerned with various methods of recovering oil from oil shale. Early in their program IGT decided to concentrate on the development of a hydrogenation process designed to give optimum production of liquid fuels from low grade shales. The "Hytort" process is the outcome of the program and a separate organization "The Hycrude Corporation" has been established to promote the "Hytort" process.

The basic conception of the "Hytort" process is pyrolysis of the shale under 600 p.s.i. hydrogen pressure, during which the hydrogen removes much of the nitrogen and sulphur and "saturates" the olefins in the oil. Additionally the oil yield is increased at the expense of the coke in the shale residue. The process produces a good quality oil ready for upgrading as a refinery feed stock.

The process uses considerable amounts of hydrogen which is obtained by the cracking of natural gas. Using a gas price of \$US 4 per million BTU, the Hycrude Corp have published a 1982 capital cost of \$368 million for a 6180 B/D plant and a production cost (1982) of \$49.5 per Bbl. This cost allows a 20% return on investment but includes a 10% tax credit.

The Hytort process has been particularly developed for the low grade somewhat coaly Devonian oil shales of eastern U.S.A. Substantial increases in oil yields are obtained only from such oil shales.

Discussion with A & J Associate (Oil Shale Consultants)

A & J Associates is a consulting organization which took over the entire laboratory system which had been set-up by the Tosco Corporation for their oil shale operations. The laboratories are extremely well equipped and are controlled by the ex-Chief Chemist of the Tosco Corp. A & J Associates handle a great deal of shale analyses and process evaluations. They are particularly well equipped to carry out small scale investigations on oil shale and shale oil. They would not comment on the behaviour of tasmanite until they had run some tests. A preliminary submission is attached (Appendix II) setting out their views on the fuel use of tasmanite and the type of program they would be prepared to undertake.

The Colorado School of MinesThe Denver Research Institute

The Colorado School of Mines have been active in oil shale technology for more than twenty years. Recently they have been concentrating their efforts on the direct hydrogenation of oil shale under autoclave conditions, the hydroextraction process. This process is discussed under "hydrogenation". The Denver Research Institute has nearly ceased work on oil shale but are interested in evaluating the environmental impact of oil shale operations. Neither organisation could see any future in the proposition of deriving chemicals from kerogen. They believed that oil shale was too inert and lacked the chemical structures to make it a useful raw material, other than for fuel use.

Discussions at the University of Utah supported the views expressed earlier in this report. It was believed that the position of oil shale, as a source of liquid fuel, had completely changed in the last few years. Whilst academic interest in oil shale research still occupies the time of some faculty, under present conditions they could not see a commercial future for the material. Most educational organisations doing research in this field seemed to be committed to high cost processes, presumably because such research provides better opportunities for complex experimentation. To a certain extent, this reasoning also applied to WRI (University of Wyoming) and DRI (University of Denver). Academic researchers tend to be immersed in their project and fail to find interest in another's problems.

Samples of tasmanite were hydrogenated at the Department of Fuels of the University of Utah. Hydrogen consumption was low and the liquid product had the typical chemical composition.

APPENDIX 1

Discussions with the following people with regard to the utilization of
Tasmanian oil shale

**Western Research Institute (Laramie),
formerly the U.S. Bureau of Mines**

James E. Speight	Deputy Managing Director and Chief Scientist
Edgar B. Smith	Manager, Process Chemistry
Francis P. Miknis	Senior Research Chemist
John F. McKay	Senior Research Chemist
Shuang-Ling Chong	Research Chemist
Jan F. Branthaver	Research Chemist
J. Ward Smith	Private Consultant

University of Utah (Salt Lake City)

George R. Hill	Eimco Professor ex. Director, U.S. Office of Coal Research
David M. Bodily	A/Dean, College of Mines and Minerals
Carl S. Minden	Consultant and Faculty Member
Larry L. Anderson	Chairman, Department of Fuels

Colorado School of Mines and Denver

Robert W. Baldwin	A/Professor, Chem. and Petroleum Engineering
Mark T. Atwood	Vice President, J and A Associates (Tosco)
Paul L. Russel	ex. Director of Research, U.S. Bur. of Mines
Joseph F. Schmidt-Collerus	Denver Research Institute

Institute of Gas Technology (Chicago)

Harlan D. F. Kirchner	Deputy Director
John C. Janka	Director, Hycrude Corporation Inc.
Michael J. Roberts	Chemical Engineer

U.S. Department of Energy - Division of Oil Shale

Douglas L. Uthaus	Acting Director of Division
Jerry A. Chapman	Assistant
and other members of the Division	

Goliath Portland Cement Co. Ltd.

David J. Covington	Works Manager
James J. Nevin	General Manager Operations

Tasmanian Department of Mines

Hugh K. Wellington	Chief Chemist
David P. Duncan	Geologist

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Tasmanian Hydro Electric Commission

Jack D. Clark Senior Power Engineer

Tasmanian Department of Agriculture

Ronald L. Richards Research Laboratories

Appendix II**J and A Associates, Inc.**

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June 29, 1984

Memo To: M. T. Atwood

From: F. B. Carlson

Subject Tasmanian Oil Shale

Economic development of Tasmanian oil shale reserves might be accomplished by using the shale as fuel for steam generation. The fluidized bed combustor would most likely be the best equipment choice for this objective. Fluid bed combustors are divided into two categories: "Fast" fluid beds and "Bubbling" beds. Generally, these would be "atmospheric" units but pressurized units may also be considered. Both varieties of fluid bed combustors have their particular advantages and disadvantages. The atmospheric, bubbling dense phase fluid bed has been used in our spent shale combustion studies and appears to have some advantages over the fast fluid bed in this application. The hybrid combustor (Circulating Solids Bed) in which combustion is accomplished (primarily) in a bubbling bed and much of the steam generation occurs in a dilute-phase bed might be the ultimate choice for producing steam with shale as fuel. The characteristics of the fuel and the recovery of the heat (i.e., steam generation, turn down, process heating), will dictate which style of combustor to use. J & A Associates are not committed to any particular combustor design.

Combustion Considerations

The Tasmanian shale (based on appearance of one sample) is a fine powder with relatively high ash content, high sulfur (2.5%) and nitrogen content (2.0%). If this behaves as Green River Formation shale, the ash will melt at relatively low temperature (2200°F) thus limiting combustor temperature. Part of the fuel is volatile and fuel losses can occur both from solids carry over and freeboard after burning. The high sulfur content will probably exceed (Stoichiometrically) the mineral carbonate content so that some base (limestone, dolomite, etc) will be required to control sulfur emissions. The high fuel nitrogen will result in very high NO_x emissions which generally are not tolerated in market areas. Nitrogen oxide emissions are most economically controlled by control of combustor parameters. Unfortunately, conditions which tend to reduce NO_x also tend to reduce combustion efficiency and to increase other emissions such as carbon monoxide. It was possible to find a set of conditions for combustion of Green River spent shale that meet all process requirements reasonably well. To find these conditions usually

requires an extensive test program with sufficiently large equipment to maintain similitude with the projected production unit. J & A Associates has such equipment available and personnel who are experienced in fluidized bed combustion of spent shales and shale. In summary, the following items are important in combustion of oil shale:

- (1) Shale particle size, decrepitation characteristics
- (2) Shale volatility
- (3) Shale composition
- (4) Fusion temperature
- (5) Reactivity of limestone, etc.
- (6) Ash removal
- (7) Heat recovery from ash, flue gas
- (8) Particulate control
- (9) Ash moisturizing and disposal
- (10) Air and fuel feed points
- (11) Turn down control
- (12) Erosion
- (13) Combustion efficiency

Some knowledge of all these factors is needed before the use of oil shale as a boiler fuel can be economically exhausted.

It is suggested that a development program be conducted in several phases as described below:

1. Evaluate the general characteristics and combustion behavior of the oil shale using the 3" bench scale fluid bed. These studies would be supported with analytical work and would determine the general behavior of the fuel, the heating value air requirements. A preliminary assessment of the fuel can be made from this work. The main objective would be, however, to approximately size the feeders, heat transfer surface etc. so that the second phase work can be carried out expeditiously. The first phase would require 100-300 lbs of shale two weeks time and an expenditure of about \$20,000.
2. The second phase of development would be conducted in an 18" diameter fluid bed and would be used to evaluate combustion efficiency, emission control, solids feeding and removal, flue gas and ash cooling, limestone usage, erosion, corrosion and heat transfer. This work could require from two to twenty weeks of testing depending on the problems encountered and the confidence in development required. This work would also, of course, be fully supported with lab analysis. The 18" combustor would be operated around the clock, 5 days per week. Three tests/day or about 12 tests, 1 week can normally be achieved (allowing for start-up, line-out). About 15 tons of shale/week would be required.

Costs for this phase of development are highly variable depending on the samples required, analysis, etc. For typical spent shale combustion tests, this would cost \$15-20,000 per week exclusive of raw materials. This work would fully assess the use of shale as a boiler fuel including combustion efficiency emissions control, ash cooling and disposal and heat transfer.

3. The third phase would involve use of the information developed in Phase 2 for the definitive boiler design. It is suggested that vendors of the system be contacted for the mechanical design of the combustor and steam system. An advantage of the approach here is that the client owns the test information and is free to approach several vendors with out becoming "locked in" via test work conducted in, and applicable to, the vendor's process. J & A Associates would coordinate and assist in process and mechanical design of the combustor to assure that process data developed in earlier tests was properly interpreted and utilized.

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FBC/eac

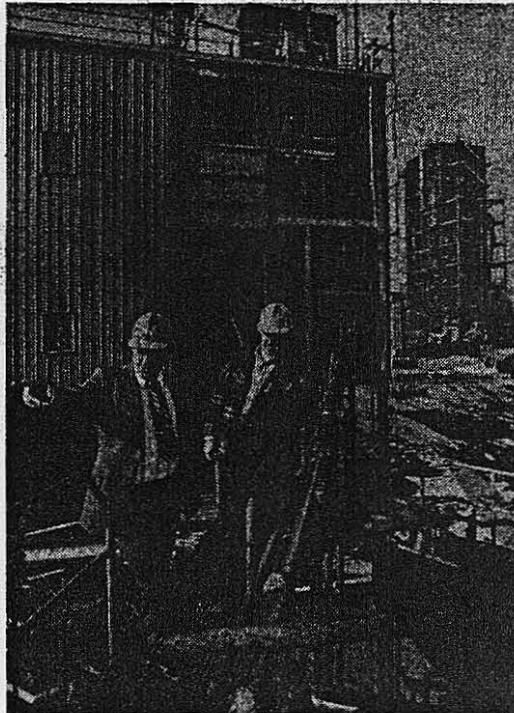
SYNFUEL LABORATORY CAPABILITIES

The Research Center laboratory offers analytical services of uncompromising quality in the following areas of special interest to synfuels development:

- Core analysis and resource appraisal
- Modified Fischer Assay; Tosco Material Balance Assay (with collection and mass balance of all solid, liquid, and gas products)
- Complete liquid and gaseous products inspection, including True Boiling Point, ASTM D-86 and D-1160 distillations; elemental and hydrocarbon analyses; product quality testing; and metals analysis by atomic absorption or x-ray fluorescence
- Assay of oil shale for dawsonite, nahcolite, and other minerals; general mineralogic analysis by x-ray diffraction
- Advanced analytical methods for trace metals, priority pollutants, and chemical constituents in ground water, process water, or wastewater
- Net energy release from combustion and accompanying reactions of carbon-bearing solids (e.g., spent shale, coal, coke)

COMPUTER SERVICES

Computer services provided include computer modeling and simulation of engineering systems, real-time data acquisition and control, database management, and microcomputer applications programming. Research Center personnel have extensive experience with DEC, Hewlett Packard, and IBM hardware and operating systems.



CONTRACT TECHNICAL SERVICES

LABORATORY BENCH SCALE PILOT PLANT



J & A Associates, Inc.
18200 West Highway 72
Golden, Colorado 80401
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J & A ASSOCIATES

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J & A Associates Contract Technical Services

J & A Associates has use of a large Research Center, located near Golden, Colorado, for commercial contract technical services. J & A Associates is made up of experienced employees utilizing familiar laboratory, pilot plant and computer facilities.

Services offered include petroleum refining; hydrocarbon evaluation, fuel chemistry; synfuel bench scale, pilot plant and laboratory processing; high pressure reactions; computer modeling and a broad range of laboratory analyses.

PETROLEUM REFINING

The Research Center maintains several oil refining pilot plant units which are used to assess the refining of petroleum liquids.

- Two-stage hydrotreater-hydrocracker
- Fluid catalytic cracker with variable reactor configuration.
- Preparative columns for atmospheric or vacuum distillations
- Micro-activity testing for FCC catalyst and feedstock evaluation
- Complete and detailed crude oil analysis service is offered for assistance in refining evaluations

Computerized database management of pilot plant experimental data is available.

Additionally, economic and engineering analysis of petroleum refining processes, and processing schemes by means of computer modeling and simulation techniques is provided by J & A Associates.

HYDROCARBON EVALUATION

Research Center personnel have extensive experience in analysis, process testing and economic evaluation of a variety of hydrocarbon liquids. These include crude and refined petroleum, coal and oil

liquids and products from biomass operations. Testing and evaluation can be conducted on laboratory scale, bench scale and pilot plant levels.

FUEL CHEMISTRY

Research Center personnel also have expertise in the chemistry of fuels. Experience includes organic reaction mechanisms, mechanisms of catalysis and theoretical kinetics. Experimental programs have been conducted on:

- Synthesis of isotopically labeled substances and determination of label distribution after processing
- Synthesis of model compounds and determination of their products and kinetic behavior
- Production of chemicals from coal
- Analysis of feedstocks and products in pilot and full scale processes

These programs have been directed toward understanding of liquefaction, gasification, and/or refining of petroleum, coal, oil shale, tar sands, and biomass materials.

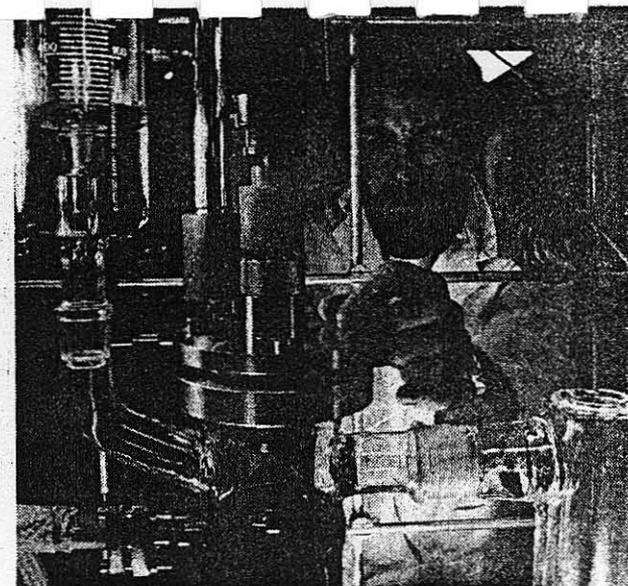
LABORATORY ANALYSES

Major Instrumentation

High resolution mass spectrometry
Gas chromatography-mass spectrometry
Nuclear magnetic resonance
Infrared spectrometry
X-Ray diffraction
X-Ray fluorescence
Atomic absorption
High performance liquid chromatography
Gas chromatography
Elemental analysis
Ion chromatography
Differential scanning calorimetry
Thermogravimetric analysis

General Analyses

The Research Center has the equipment and skilled personnel for nearly all phases of petroleum, oil shale, coal, water and minerals analysis.



SYNFUEL, BENCH-SCALE AND PILOT PLANT FACILITIES

Bench Scale Testing

Bench-scale apparatus is available for tests of feedstocks, operating conditions, and products and processes that involve pyrolysis, combustion, or gasification. Each of the units can be run with any carbonaceous feedstock, including oil shale, tar sands, coal, or lignite. The individual units include:

- Four-inch heated screw retort for continuous pyrolysis
- Two fluid bed reactors for pyrolysis and combustion studies
- A batch mode rotating retort

Pilot Plant Facilities

Several pilot-scale facilities are available for testing feedstocks and processes. These plants have processed a variety of feedstocks including rich and lean oil shales, tar sands, bituminous coal and diatomaceous earth.

- A 24-TPD indirect fired pyrolysis pilot plant
- A 6-TPD Hydrocarbon Solids Process (HSP) pilot plant for advanced retorting and heat recovery.
- A 2-TPD fluid bed gasifier

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