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# COAL AS AN ENERGY SOURCE IN RECOVERY AND UPGRADING OF CANADIAN HEAVY OILS AND TAR SANDS

by

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## SUMMARY

The use of coal has been considered as a supplemental energy source in manufacturing synthetic crude oil from the Canadian oil sand deposits. The amount of coal required varies substantially depending upon the combination of recovery and upgrading methods used to produce the synthetic crude. The choice between surface mining and in-situ recovery methods depends upon the nature of the deposit. The process economics which govern the selection of an upgrading method are controlled primarily by the energy balance. For example some upgrading methods produce by-product fuel which can be used for process heat.

The cost of this generated fuel versus make up fuel (e.g. coal) influences the choice of the upgrading process. When the surface mining method was used for recovery, flexicoking was the chosen upgrading process. Flexicoking generates a substantial quantity of by-product fuel which can be used in the hot-water bitumen-sand separation process used in conjunction with surface mining. In contrast hydrocracking produced so little by-product fuel that some of the synthetic crude oil product had to be used for process heat. For in-situ steam injection hydrocracking was the preferred upgrading process. A larger quantity of coal could be used as make up fuel. With flexicoking a larger quantity of bitumen had to be recovered to produce the by-product fuel. Hydrocracking was also preferred when the in-situ combustion method was used. In-situ combustion produces both bitumen and fuel gas. This fuel gas provided almost all the required process heat. The by-product fuel gas produced from flexicoking exceeded the process requirements.

Different make up fuels were compared. Direct combustion of coal was preferred. Combustion of bitumen coupled with sulphur dioxide removal facilities was another alternative. The generation of synthetic natural gas from coal was also considered, both at the mine mouth and at the upgrading site.

Substantial quantities of coal could be required. For example the amount of coal required for the steam injection plus hydrocracking combination could approach 20 percent of the current Canadian production of thermal coal.

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## The Canadian Oil Sands Industry

The Canadian oil sand deposits contain about one trillion ($10^{12}$) barrels of bitumen and heavy oil. Approximately 30% of the resource is considered to be recoverable using present technology. This is roughly equivalent to one half of the total world reserves of conventional petroleum.

The oil sand deposits are geological formations composed of bitumen, sand and clay. The deposits are spread over many thousands of square kilometers. At some locations they are at the surface. In other locations they occur at depth. Approximately 15% of the material is close enough to the surface (45 m or less overburden) to be recovered by surface mining techniques. The portions of the deposit which contain more than 180 m of overburden can be recovered by in-situ methods. The material having an overburden between 45 and 180 m represents an area for which recovery methods have not been fully developed. Generally less than 15% of the bitumen-sand-clay mixture is bitumen. After the bitumen has been recovered from the deposit it requires substantial conversion before it will meet the specifications of conventional crude oil.

Two commercial plants have been constructed. In 1967 Great Canadian Oil Sands (SUNCOR) began operating a plant which was designed for 45,000 barrels per day. This plant cost approximately 350 million dollars for construction. In 1979 Syncrude Limited began operating a plant having a capacity of 125,000 barrels per day. This plant cost 2.5 billion dollars. Both of the existing plants use the surface mining technique to recover the bitumen. Two other groups are actively working on plans for additional oil sands plants. One will use the surface mining recovery technique and the other will use an in-situ steam injection technique. Each plant is estimated to cost between four and five billion dollars.

The oil sands plants still have technical problems. Some of these relate to mining itself. The hot water separation process, used in conjunction with surface mining, produces a water effluent containing fine particles which do not settle. This water continues to accumulate in tailings ponds which are becoming progressively larger. Also there have been periodic operating difficulties associated with the coking units. These downtime periods have a direct effect on production rate.

The percentage of the bitumen converted to synthetic crude oil can be increased if a make up fuel is used to provide the energy necessary for the processing units. The two plants currently in operation use natural gas. It has been proposed that coal be used to provide make up energy for the oil sand plant which will use steam injection to recover the bitumen. Without the use of coal almost one third of the recovered bitumen would have to be burned to generate the steam for recovery. This study was performed in order to assess the role of coal as an energy source in the production of synthetic crude from oil sands.

## Description of Recovery and Upgrading Techniques

Three methods of recovering bitumen from the deposit were considered in this study: surface mining, steam injection and combustion. Bucket wheel excavators or draglines are used for surface mining the oil sand material. It is then transported to a hot water extraction plant where the bitumen and the sand are separated using hot water, caustic and low pressure steam. As mentioned above a large quantity of fine solid material remains in the water which is discharged to the tailing ponds. The tailings water also contains approximately 7 to 9% of the original bitumen. If the dykes around the tailing ponds were to rupture, severe environmental damage could occur.

In the steam injection recovery method high temperature steam is injected into the geological formation. The formation is warmed thereby decreasing the viscosity of the bitumen. It can then flow through a producing well to the surface. In this study it was assumed that by-products from upgrading would be used to generate steam and that coal would be imported as a make up fuel for steam generation. The producing wells bring a certain amount of the water and condensed steam in addition to bitumen up to the surface. This water contains substantial quantities of dissolved solids which must be removed before the water can be reconverted to steam and placed into the formation again. A slight variation of the injected steam technique involves the combined injection of steam and inert gas which is said to increase the production rates from each well and to decrease the required water-to-oil ratio. The steam injection technique is the most highly developed type of in-situ technology and has been used commercially in Venezuela and California. Steam injection has been successfully demonstrated in a pilot operation by one of the oil sand development companies.

The in-situ combustion recovery technique is at an earlier stage of development. In this method air is injected into the formation where combustion of the air with some of the oil occurs. Again the formation is heated thereby decreasing the viscosity of the hydrocarbon bitumen which can then be pumped to the surface. Combustion has some potential problems. The generation of high temperatures can cause damage to the well bore equipment. Also oil-water emulsions are produced which are sometimes difficult to break. In addition to producing bitumen this technique also produces a substantial quantity of low calorific value fuel gas which can be used as a make up fuel.

Two types of upgrading technique have been considered for use in oil sands complexes. The coking processes involve heating the bitumen to temperatures such that pyrolysis occurs. The large molecules are cracked to form smaller molecules which enter the vapour phase and are removed from the coking unit. The residue from this process is a mass of solid carbonaceous material known as coke. The coking processes are basically carbon removal processes. The bitumen is converted into distillates which have greater hydrogen contents than the feedstock, and into coke which is almost devoid of hydrogen. The flexicoking process converts the coke into a low calorific value fuel gas.

Hydrocracking, the other upgrading technique is a hydrogen addition process. In this case there is no solid product produced. Instead hydrogen gas is incorporated into the bitumen to produce a liquid having a higher hydrogen to carbon ratio than the feedstock. The advantage of hydrocracking processes over the coking processes is that a larger quantity of distillate liquid is produced. Furthermore the distillate obtained by hydrocracking is of superior quality. One disadvantage is that hydrocracking processes are somewhat more capital intensive. Also they require hydrogen, which is expensive. With rising prices for petroleum the additional yield of product has to provide a return for the incremental investment cost. Another attribute of the hydrocracking process is that it is generally easier to operate and therefore less downtime is expected.

### Engineering and Cost Parameters

In this study several combinations of recovery processes, upgrading processes, and make up energy fuels were considered. Each case was to produce 100,000 barrels per calendar day (B/CD) of synthetic crude oil. The product was to be refined to a quality comparable to that being produced by the two existing commercial plants. The various units were given service factors varying between 0.9 and 0.95. In the one case where bitumen was used as a make up fuel sulphur dioxide scrubbing facilities were installed to reduce atmospheric emissions.

Calculations were done on the basis of several assumptions: loans for the oil sands complex were to be available at 8¼% and a return of 13¼% was to be available for the equity provided by shareholders. It was assumed there would be a 90/10 debt to equity ratio. This required an overall rate of return of 8¾%. Coal was assumed to be available at $7.40 per metric ton at the mine mouth. All costs were taken to be valid for the first quarter of 1977, and are reported in Canadian dollars. No royalties were charged and taxes were taken to be 50 percent.

The synthetic crude costs required to earn the above rate of return are shown in Tables 1 and 2 for each of the cases. Three recovery methods, two upgrading processes and three make up fuels were considered. Partial material balances for the cases are shown in Figures 1 to 4. In each case the upgrading processes included a naphtha hydrotreater, a gas-oil hydro-

## TABLE 1

## EFFECT OF RECOVERY AND UPGRADING METHODS ON SYNTHETIC CRUDE COST *

| CASE | RECOVERY TECHNIQUE | UPGRADING PROCESS | SYNTHETIC CRUDE COST $/Bbl |
|---|---|---|---|
| 1 | Mining | Hydrocracking | 11.86 |
| 2 | Mining | Flexicoking | 11.54 |
| 3 | Steam Injection | Hydrocracking | 12.35 |
| 4 | Steam Injection | Flexicoking | 12.53 |
| 7 | Combustion | Hydrocracking | 12.49 |
| 8 | Combustion | Flexicoking | 13.22 |

* Coal is used as the make-up energy source in all cases

## TABLE 2

## EFFECT OF MAKE-UP ENERGY SOURCE ON SYNTHETIC CRUDE COST **

| CASE | MAKE-UP ENERGY SOURCE | SYNTHETIC CRUDE COST $/Bbl |
|---|---|---|
| 3 | Coal | 12.35 |
| 5 | Bitumen | 12.71 |
| 6a | SNG-Upgrading Site | 17.17 |
| 6b | SNG-Mine Mouth | 16.06 |

** Steam injection and hydrocracking are used in all cases

FIGURE 1

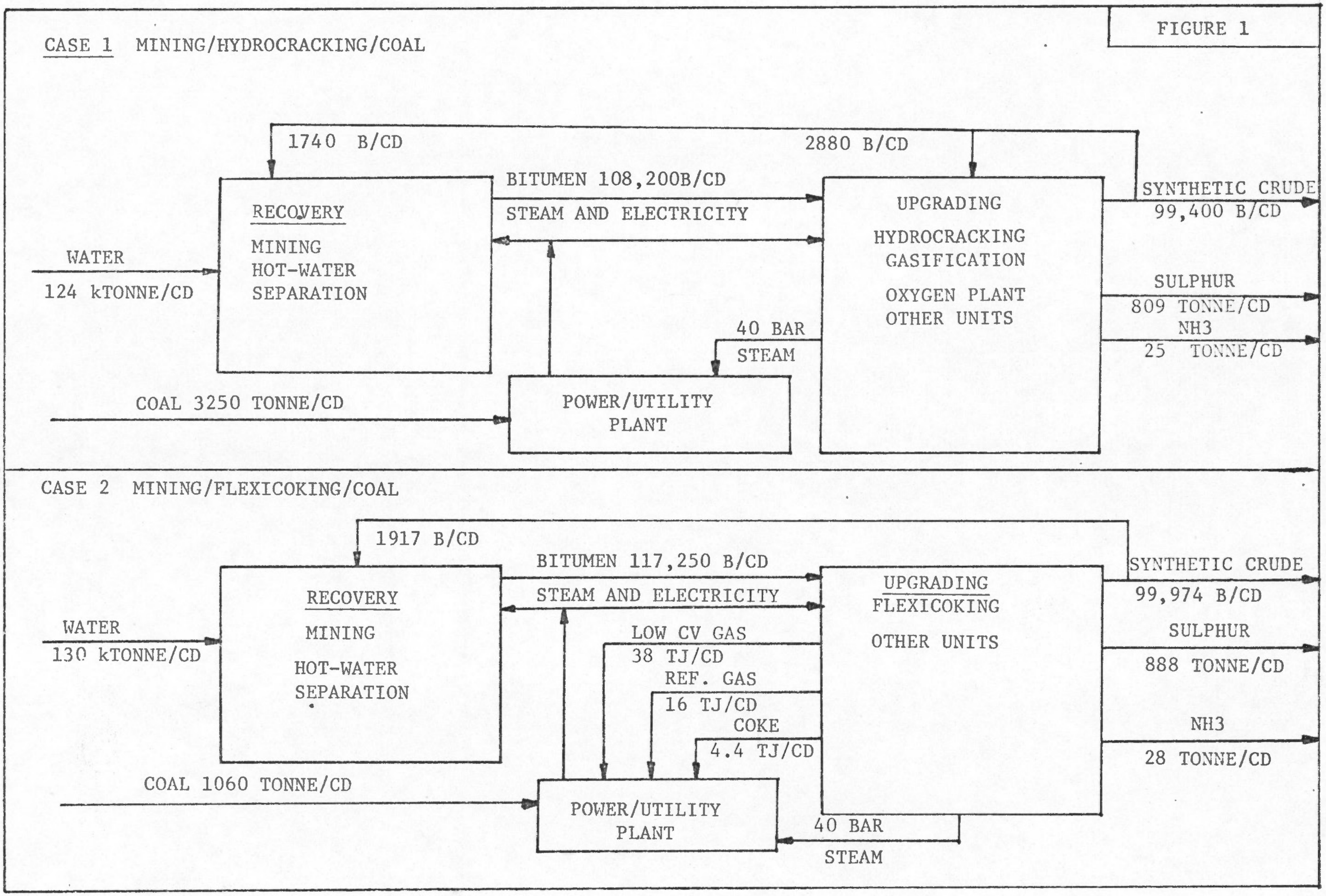
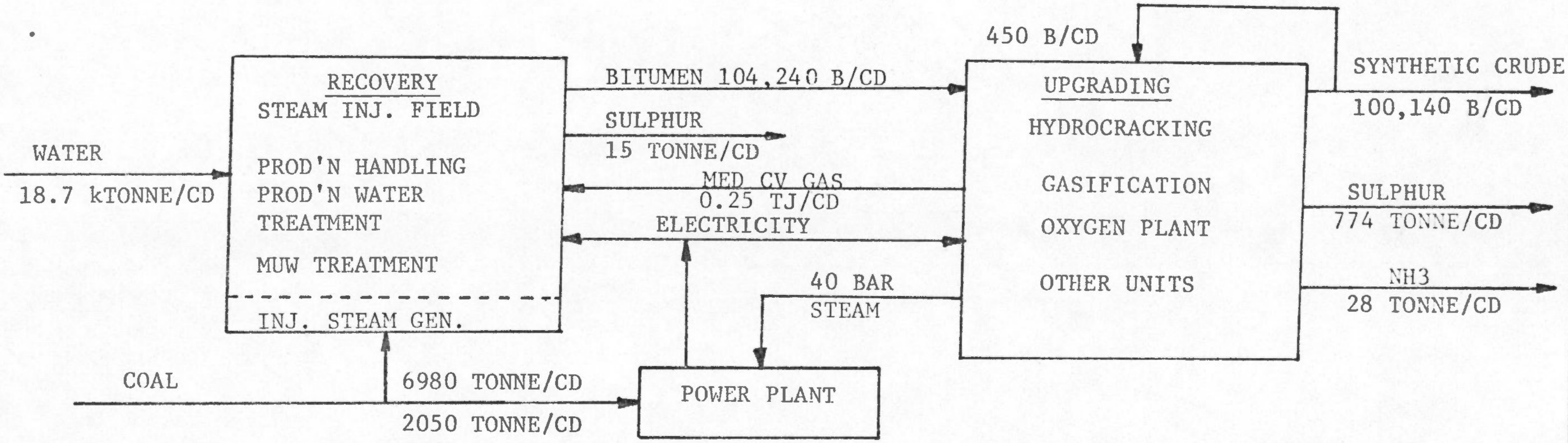

CASE 1 MINING/HYDROCRACKING/COAL
1740 B/CD
2880 B/CD
RECOVERY
MINING
HOT-WATER
SEPARATION
BITUMEN 108,200B/CD
STEAM AND ELECTRICITY
UPGRADING
HYDROCRACKING
GASIFICATION
OXYGEN PLANT
OTHER UNITS
SYNTHETIC CRUDE
99,400 B/CD
SULPHUR
809 TONNE/CD
NH3
25 TONNE/CD
WATER
124 kTONNE/CD
40 BAR
STEAM
COAL 3250 TONNE/CD
POWER/UTILITY
PLANT
CASE 2 MINING/FLEXICOKING/COAL
1917 B/CD
BITUMEN 117,250 B/CD
STEAM AND ELECTRICITY
RECOVERY
MINING
HOT-WATER
SEPARATION
UPGRADING
FLEXICOKING
OTHER UNITS
SYNTHETIC CRUDE
99,974 B/CD
SULPHUR
888 TONNE/CD
NH3
28 TONNE/CD
WATER
130 kTONNE/CD
LOW CV GAS
38 TJ/CD
REF. GAS
16 TJ/CD
COKE
4.4 TJ/CD
COAL 1060 TONNE/CD
POWER/UTILITY
PLANT
40 BAR
STEAM

FIGURE 2

CASE 3 STEAM INJ./HYDROCRACKING/COAL



CASE 4 STEAM INJ./ FLEXICOKING/COAL

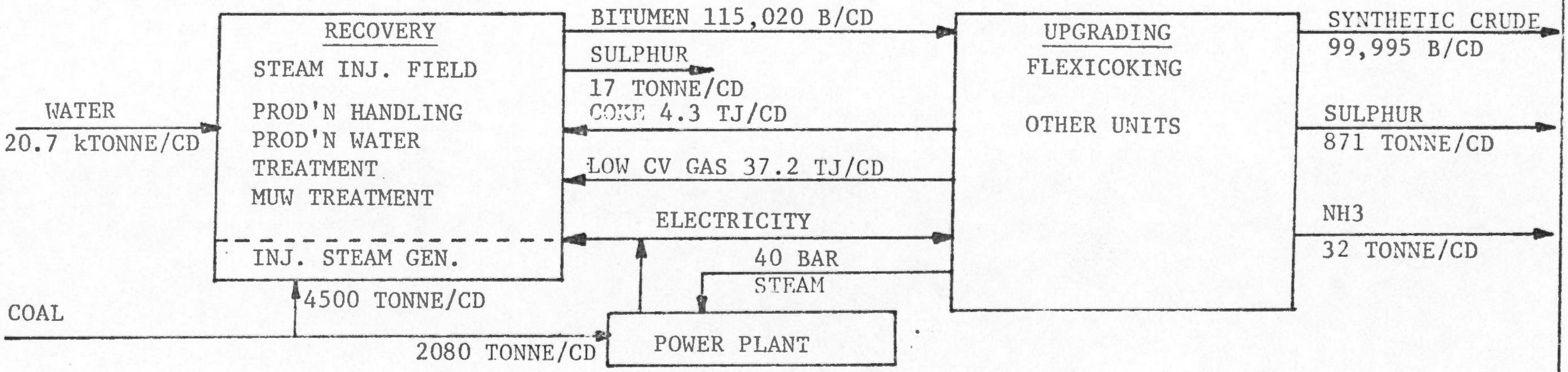
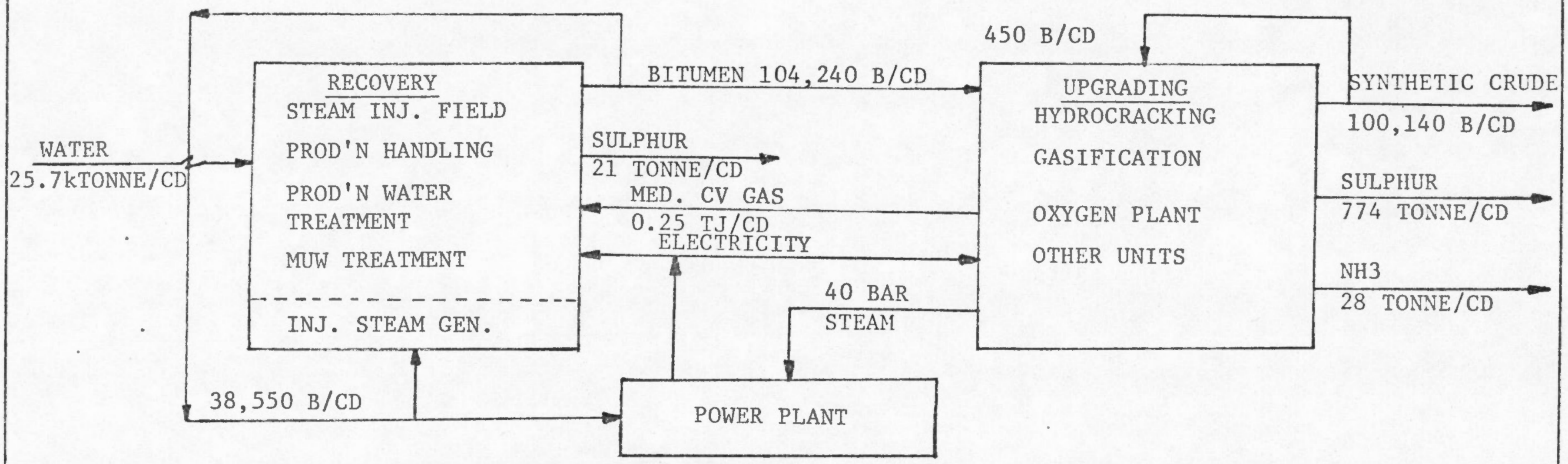


FIGURE 3

CASE 5 STEAM INJ./HYDROCRACKING/BITUMEN



CASES 6A + 6B STEAM INJ./HYDROCRACKING/SNG FROM COAL

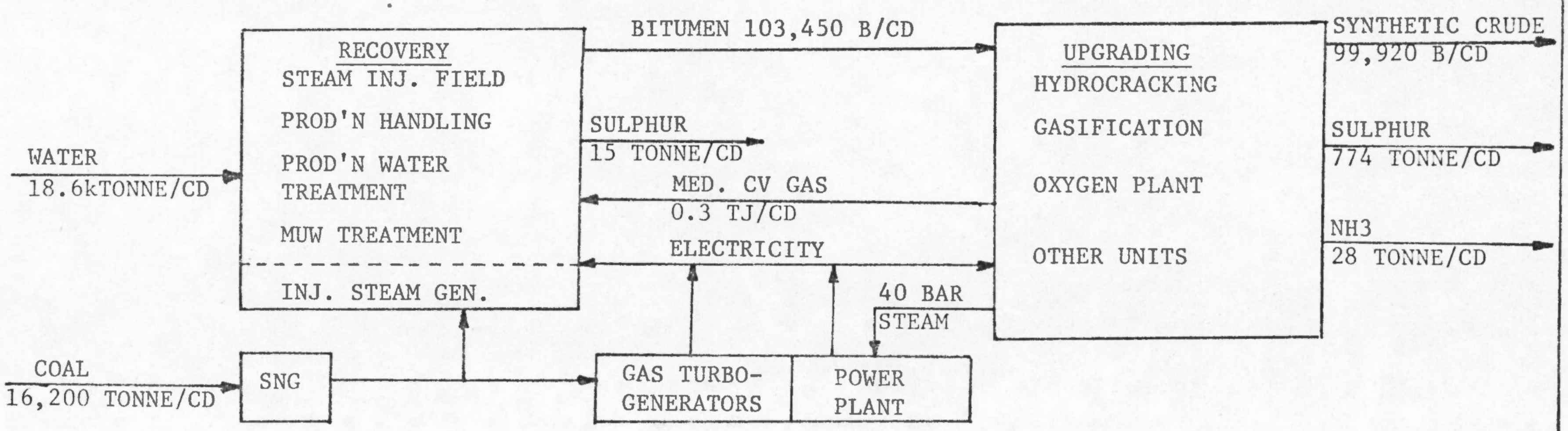
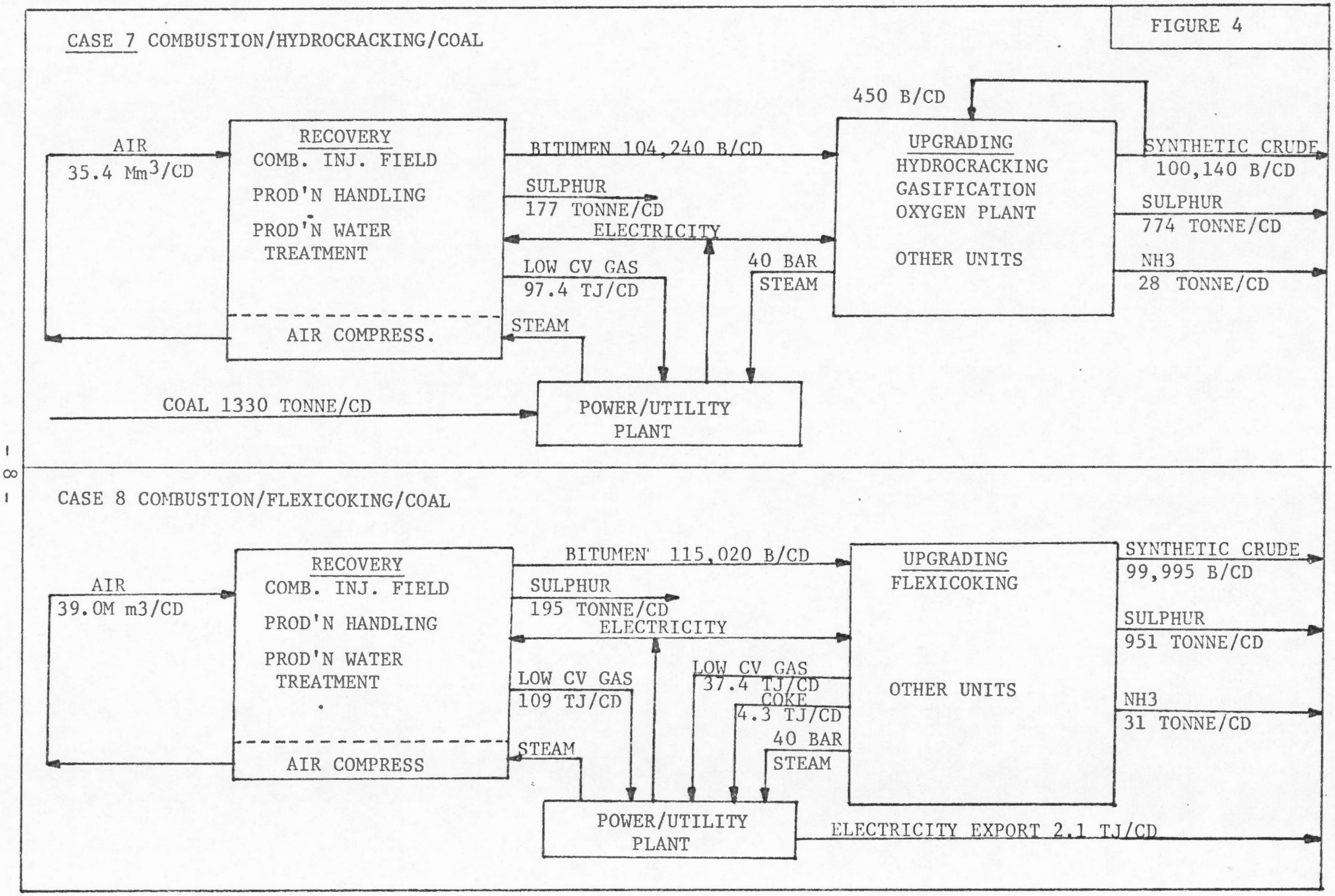


FIGURE 4



CASE 7 COMBUSTION/HYDROCRACKING/COAL
AIR
35.4 Mm3/CD
RECOVERY
COMB. INJ. FIELD
PROD'N HANDLING
PROD'N WATER TREATMENT
AIR COMPRESS.
BITUMEN 104,240 B/CD
SULPHUR
177 TONNE/CD
ELECTRICITY
LOW CV GAS
97.4 TJ/CD
STEAM
40 BAR
STEAM
450 B/CD
UPGRADING
HYDROCRACKING
GASIFICATION
OXYGEN PLANT
OTHER UNITS
SYNTHETIC CRUDE
100,140 B/CD
SULPHUR
774 TONNE/CD
NH3
28 TONNE/CD
COAL 1330 TONNE/CD
POWER/UTILITY PLANT
CASE 8 COMBUSTION/FLEXICOKING/COAL
AIR
39.0M m3/CD
RECOVERY
COMB. INJ. FIELD
PROD'N HANDLING
PROD'N WATER TREATMENT
AIR COMPRESS
BITUMEN 115,020 B/CD
SULPHUR
195 TONNE/CD
ELECTRICITY
LOW CV GAS
109 TJ/CD
STEAM
LOW CV GAS
37.4 TJ/CD
COKE
4.3 TJ/CD
40 BAR
STEAM
UPGRADING
FLEXICOKING
OTHER UNITS
SYNTHETIC CRUDE
99,995 B/CD
SULPHUR
951 TONNE/CD
NH3
31 TONNE/CD
POWER/UTILITY PLANT
ELECTRICITY EXPORT 2.1 TJ/CD

## TABLE 3

## EFFECT OF RECOVERY AND UPGRADING METHODS ON CAPITAL COST (CAN.$X10$^{-3}$)

| RECOVERY TECHNIQUE | MINING | | STEAM INJECTION | | COMBUSTION | |
|---|---|---|---|---|---|---|
| UPGRADING PROCESS | HYDRO-CRACKING | FLEXI-COKING | HYDRO-CRACKING | FLEX-COKING | HYDRO-CRACKING | FLEXI-COKING |
| CASE NUMBER | 1 | 2 | 3 | 4 | 7 | 8 |
| Mining | 540000 | 572000 | | | | |
| Hot Water | 232000 | 245000 | | | | |
| Steam Injection Field | | | 1097920 | 1202358 | | |
| Injection Steam Generation Plant | | | 293000 | 295320 | | |
| MUW Treatment | | | 7500 | 8000 | | |
| Production Handling | | | 55680 | 59480 | 82310 | 87724 |
| Produced Water Treatment | | | 58636 | 64688 | 7200 | 7950 |
| In-situ Combustion Field | | | | | 1639812 | 1816311 |
| Air Compressors | | | | | 208406 | 222161 |
| Hydrocracking | 78710 | | 79380 | | 79380 | |
| Flexicoking | | 175750 | | 180680 | | 180680 |
| Naphtha Hydrotreating | 18500 | 22465 | 18056 | 22173 | 18056 | 22173 |
| Gas Oil Hydrotreating | 59120 | 59930 | 57051 | 59151 | 57051 | 59151 |
| Hydrogen Manufacturing Plant | 96000 | 73550 | 93680 | 72594 | 93680 | 72594 |
| Pitch Partial Oxidation | 106110 | | 50350 | | 50350 | |
| Oxygen Plant | 39340 | | 36600 | | 39310 | |
| $H_2S$ Removal | 27000 | 30150 | 26352 | 29759 | 26352 | 29759 |
| Sulfur Plants | 19250 | 17500 | 18788 | 17273 | 18788 | 17273 |
| Utility Plant | 185150 | 183420 | | | 148350 | 159850 |
| Power Plant | | | 130000 | 143000 | 56000 | 64000 |
| Tankage Interconnecting Piping | 177600 | 200400 | 184200 | 197873 | 193200 | 206873 |
| Miscellaneous | 98918 | 93198 | 129172 | 132596 | 121044 | 121367 |
| Camp | 255700 | 241842 | 336800 | 355500 | 325507 | 340837 |
| Contractor's Overhead and Profit | 166990 | 165829 | 140116 | 144537 | 131440 | 137288 |
| Total Capital Cost | 2100388 | 2081034 | 2813281 | 2984982 | 3296236 | 3545991 |

## TABLE 4

## EFFECT MAKE-UP ENERGY SOURCE ON CAPITAL COST (CAN.$X10$^{-3}$)

| MAKE-UP ENERGY SOURCE | COAL | BITUMEN | SNG AT UPGRADING SITE | SNG AT MINE MOUTH |
|---|---|---|---|---|
| CASE NUMBER | 3 | 5 | 6a | 6b |
| Steam Injection Field | 1097920 | 1507281 | 1088585 | 1088585 |
| Injection Steam Generation Plant | 293000 | 293000 | 234600 | 234600 |
| MUW Treatment | 7500 | 10000 | 7500 | 7500 |
| Production Handling | 55680 | 68652 | 55680 | 55680 |
| Produced Water Treatment | 58636 | 81700 | 58163 | 58163 |
| Hydrocracking | 79380 | 79380 | 79112 | 79112 |
| Naphtha Hydrotreating | 18056 | 18056 | 17982 | 17982 |
| Gas Oil Hydrotreating | 57051 | 57051 | 57465 | 57465 |
| Hydrogen Manufacturing Plant | 93680 | 93680 | 85492 | 85492 |
| Pitch Partial Oxidation | 50350 | 50350 | 49600 | 49600 |
| Oxygen Plant | 36600 | 36600 | 36110 | 36110 |
| SNG operation | | | 823539 | 883539 |
| $H_2S$ Removal | 26352 | 26352 | 26244 | 26244 |
| Sulfur Plants | 18788 | 18788 | 18711 | 18711 |
| Power Plant | 130000 | 153000 | | |
| Tankage Interconnecting Piping | 184200 | 202620 | 184200 | 184200 |
| Miscellaneous | 129172 | 133156 | 105422 | 105422 |
| Camp | 336800 | 371000 | 478463 | 478463 |
| Contractor's Overhead and Profit | 140116 | 163099 | 199250 | 199250 |
| Total Capital Cost | 2813281 | 3363765 | 3606118 | 3666118 |

treater, hydrogen manufacturing facilities, hydrogen sulphide removal facilities and sulphur plants. The synthetic crudes prices are directly related to the capital cost of the processing equipment. Depreciation on capital overwhelms all the other items which contribute to the annual operating cost. Itemized listings of capital cost by process are shown in Tables 3 and 4 for each of the cases studied. With the exception of field expenses in the in-situ recovery cases, all of the capital must be used at the beginning of the project. The capital expenditure for field facilities was spread over the life of the project. Steam injection and combustion wells were assumed to have useful lives of 6 and 7 years respectively.

Process and cost data were obtained from two primary sources. Most of the information was obtained from process licensors. Yields for the coking process were those for EXXON flexicoking. Hydrocracking yields were obtained from the CANMET pilot plant. The cost information provided by the process licensors for upgrading technology was verified from detailed calculations. For these processes cost estimates were obtained for each major item of equipment.

## Comparison of Recovery and Upgrading Technologies

The recovery and upgrading technologies can be compared in terms of the synthetic crude costs in Table 1. The variation in these costs with technology type can be understood in terms of the capital costs of a particular processing unit and can be partially related to the material balances shown in Figures 1, 2 and 4.

The energy make up source was coal for all of the cases shown in Table 1 except case 8. Case 8 did not require any make up energy. Cases 1 and 2 considered surface mining, 3 and 4 steam injection and cases 7 and 8 combustion. The results indicated surface mining is certainly less expensive than either of the in-situ techniques. Steam injection is marginally less expensive than combustion. Of the two upgrading processes hydrocracking was the preferred upgrading process for both of the in-situ recovery methods whereas flexicoking was preferred in the case of the surface mining. The lower synthetic crude price for surface mining is related to the lower capital cost shown in Table 3. If one subtracts the cost of the recovery method from the total capital costs in Table 3 the resultant costs are similar in every case. The capital cost differences can be related to the investment for recovery facilities. The investment for surface mining is made at the beginning of the project. In contrast the investments for both the combustion and steam injection fields are spread out over the life of the project. It was previously noted that steam and combustion wells have useful lifetimes of 6 and 7 years respectively. The capital cost for the in-situ cases shown in Table 3 is the total over the entire lifetime of the project. In computing the synthetic crude price delayed investment was discounted. Straight line depreciation of 4 percent was used.

The significant differences in the two surface mining cases are apparent in Table 3 and in Figure 1. The capital cost for hydrocracking, pitch partial oxidation and the oxygen plant exceeds that for flexicoking. Also a larger capacity hydrogen plant is required with hydrocracking. The costs for the other units are similar in both cases. Figure 1 shows that almost 3 percent of the synthetic crude product was used as fuel in the upgrading units for the hydrocracking case. The process furnaces with the upgrading units do not accept coal as a fuel. If it was not necessary to burn the synthetic crude in the processing units, the capital cost for the total complex could have been reduced by 3 percent.

For the two in-situ methods hydrocracking has slightly lower capital cost than the flexicoking alternatives as shown in Table 3. One of the reasons that the hydrocracking upgrading process is less expensive than flexicoking may be seen by comparing cases 3 and 4 (Figure 2) and by comparing cases 7 and 8 (Figure 4). Cases 4 and 8 using flexicoking both require larger quantities of bitumen to enter the upgrading units in order to manufacture 100,000 barrels a day of synthetic crude. The reason for this is that the coking process produces a lower yield of distillate liquids than the hydrocracking process. Instead flexicoking produces a large quantity of low calorific value fuel gas. This fuel gas can be used to generate steam or power. The hydrocracking process does not make this low calorific fuel gas and so larger quantities of coal are used to generate steam and electricity. The smaller quantity of bitumen required (from the recovery method) when hydrocracking is used contributes to the low capital cost. In comparing cases 7 and 8 there is so much low calorific fuel gas produced by the combustion recovery method that a large percentage of the utility and power requirements can be generated from it. In case 8 there is no requirement for make up energy in the form of coal. In fact there is so much low calorific fuel gas that surplus electricity is exported.

Cases 3 and 7 use less bitumen and more coal than cases 4 and 8 to make the same synthetic crude product. In these terms hydrocracking allows coal to be converted into crude oil, even though the coal never enters the hydrocracking unit. Comparing cases 3 and 4 there are approximately 2 barrels of oil made per incremental tonne of coal whereas cases 7 and 8 indicate 10 barrels per tonne.

The quantity of coal used as make up energy shown in Figures 1, 2 and 4 can be compared in each of the cases. For both of the in-situ recovery methods, the more coal imported the lower the cost of the synthetic crude. This trend was not observed with surface mining. However, this may have been influenced by the use of synthetic crude as fuel when hydrocracking was used for upgrading.

## Comparison of Make up Fuels

Three different types of make up fuel were compared, coal (case 3) bitumen (case 5) and synthetic natural gas (SNG) (cases 6a and 6b). In case 6a coal was transported from the mine mouth to the upgrading site. At the upgrading site it was converted into synthetic natural gas and then used as a fuel. In case 6b coal was converted into synthetic natural gas at the mine mouth and then transported by a pipeline to the upgrading site where the SNG was used as an energy source.

Table 2 shows costs of synthetic crude oil for each of the different make up fuels. Coal provides the least expensive synthetic crude oil. It is more expensive when bitumen is the make up fuel. The use of SNG results in the highest costs for synthetic crude oil. These results are reflected in the capital costs shown in Table 4. Using bitumen as a make up fuel requires more capital than using coal because a greater amount of bitumen must be produced. This may be seen by comparing cases 3 and 5 in Figures 2 and 3. The additional equipment required to produce the additional bitumen in case 5 is responsible for the additional capital shown in Table 4.

The two cases which use SNG were substantially more expensive. According to Table 2 there is an advantage to transporting synthetic natural gas from the mine mouth to the upgrading site rather than transporting the coal to the upgrading site and making the synthetic natural gas there. Table 4 shows that the capital costs for the two SNG cases are the largest. The capital cost is the greatest when the SNG is transported from the mine mouth to the upgrading site (case 6b). This is because a pipeline must be constructed. However, the synthetic crude oil is less expensive (Table 2) when SNG is pipelined than when coal is transported and SNG manufactured at the upgrading site. This is because extremely large quantities of coal must be transported to manufacture the SNG. A comparison of case 6 in Figure 3 with case 3 in Figure 2 shows that almost twice as much coal must be used when SNG is manufactured. The above comparison indicates that the least expensive synthetic crude results when coal is transported to the upgrading site and used "as is" for the make up fuel.

## Interaction of Recovery and Upgrading Processes

The recovery process chosen (surface mining or in-situ) depends on the nature of the deposit considered. However, this study indicates that the coking process has an advantage when in-situ recovery techniques are used. In other words the choice of an upgrading process is wholly dependent upon what type of recovery technique has been used.

The make up fuel source seems to have a large effect on the various costs. The in-situ recovery cases permit the use of substantial quantities of coal as an import energy source with hydrocracking as the preferred upgrading process. For the case using surface mining and hydrocracking, the amount of coal which could be used was limited. Coal cannot be burned in process furnaces. As a result the much higher priced synthetic crude was used instead of coal.

Thus it is apparent that all of the costs depend upon the make up energy source. In those instances where coal could be used in large quantities the hydrocracking process was found to be preferable. However, in a situation where coal use was limited flexicoking was the preferred upgrading process.

## Coal in the Energy Balance

The role of coal in the energy balance for recovery and upgrading oil sands must be seen in the context of overall Canadian coal production. Case 3 can be chosen as a basis of comparison for two reasons, i) the greatest percentage of the oil sand deposits will have to be recovered by in-situ techniques, and ii) steam injection is the most advanced in-situ technology at present. Case 3 indicates that 9000 tonnes per calendar day of coal are required. This is almost 20% of 1978 Canadian thermal coal production (47,000 tonnes per calendar day). Should five or six oil sand plants be operating by the year 2000, their coal requirements will significantly influence coal supply and demand in Canada.

## Acknowledgement

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