7. Economic Analysis Results

7.1 Supply Cost Curves

The capital and operating cost data were determined by examining historical costs for conventional heavy oil projects. The supply costs for typical wells, categorized based on recovery amounts over the life of the well, are summarized and quoted as Canadian dollars, constant, year 2000 (Figure 7.1). The supply costs ranged from a high of approximately $270/m^3$ for a well that produces a cumulative total of 2 500 m^3 to a low of $34/m^3$ for a well that produces a cumulative total of 100 thousand m^3. For a well that produces a cumulative total of 10 thousand m^3, the average supply costs are in the range of $70-80/m^3$. The high supply costs for the low productivity wells are the result of a combination of high capital costs and low oil recovery. The supply costs decrease sharply with an increasing amount of recovery, especially in the recovery range of two to 20 thousand m^3. Beyond the 20 thousand m^3 range, supply costs are influenced more by operating costs than by capital expenditures.

7.1.1 Supply Cost Curve for Remaining Recoverable Conventional Heavy Oil

Figure 7.2 shows the supply costs for the three zones and overall remaining recoverable conventional heavy oil. It indicates that supply costs ranged from approximately $34 to $270/m^3$ and approximately 80 percent of the remaining recoverable could be recovered at a supply cost of $100/m^3$ or less. Similarly, 97 percent of Jurassic, 75 percent of Cretaceous and 88 percent of

FIGURE 7.1

Supply Cost Curve for Typical Wells

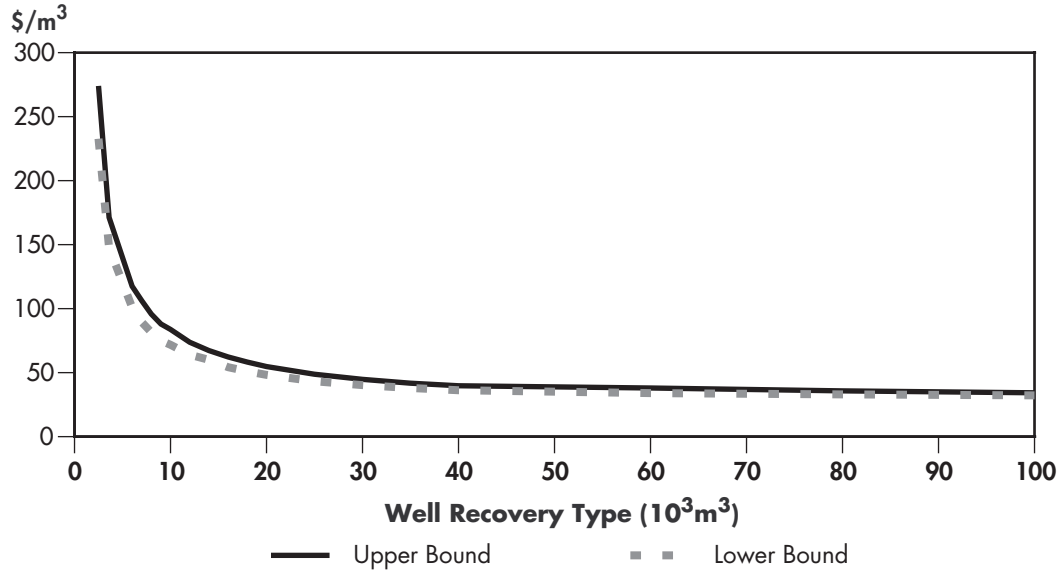
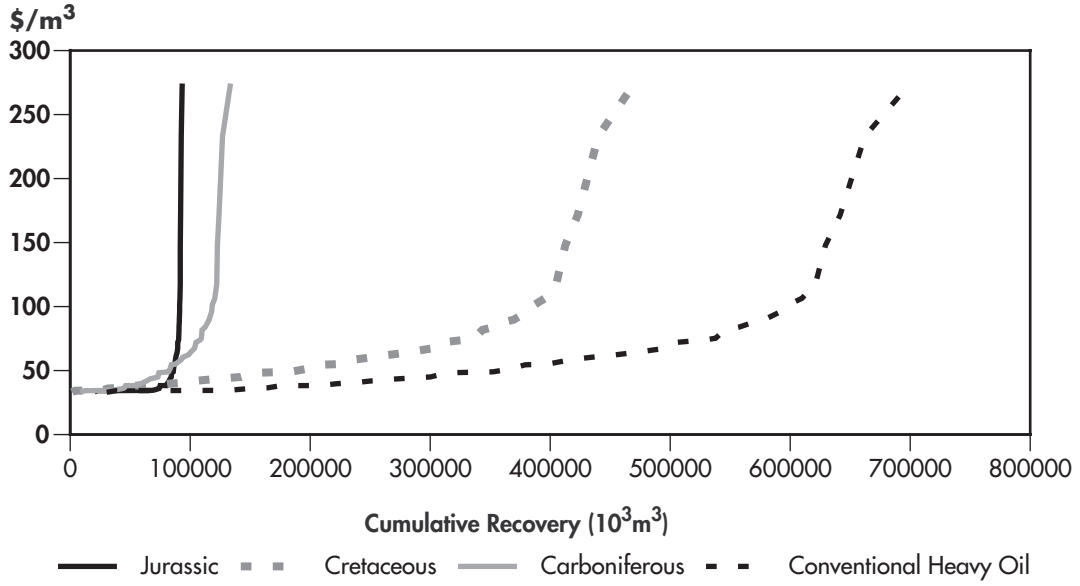


FIGURE 7.2

Supply Cost Curve – Conventional Heavy Oil



Carboniferous recoverable volumes could be recovered at a supply cost of $100/m^3 or less. The overall mean supply costs are approximately $41/m^3 for Jurassic, $70/m^3 for Permian and $98/m^3 for Cretaceous.

7.1.2 Supply Cost Curves for Individual Plays

The mean supply costs for an individual play reflect each play's unique geology, reservoir properties and development plans (Table 7.1).

Based on historical information, over 30 percent of the wells in the Cretaceous Upper Mannville play produced a total of less than one thousand m^3 while approximately one-half of the wells produced a total of less than three thousand m^3 (Figure 7.3). Only two percent of the cumulative production came from wells that produced less than one thousand m^3, and eight percent of the cumulative production was sourced from wells that produced less than three thousand m^3. Therefore, the costs of producing from low productivity wells are offset by the production from high productivity wells in each play. The mean supply costs for each individual play are a reflection of the cumulative frequency distribution for different wells in the same play. The mean supply costs for the Upper Mannville play is about $92/m^3 (Figure 7.4).

TABLE 7.1

Supply Cost Curve for Zones and Plays

Zone - Play	Supply Costs		
	Low	High	Mean
Carboniferous			70
Rundle Sweetgrass	80	92	91
Mississippian Subcrop	85	98	97
Souris-Tilston	118	138	125
Frobisher-Alida	61	70	68
Midale	47	53	51
Ratcliffe	55	62	61
Bakken	64	73	69
Jurassic			41
Sawtooth	42	46	45
Shaunavon	36	38	38
Roseray-Success	41	44	43
Cretaceous			83
Lower Mannville	81	93	90
Upper Mannville	83	96	92
Detrital	93	108	107
Ostracod	95	111	110
Glauconitic	42	46	44
Dina	79	91	84
Cummings	91	106	102
Colony to Lloydminster	79	91	87
Cantuar	52	58	58

7.2 Summary

The supply cost estimates for each play are based on the analysis of historical production of individual wells and the development of typical well production profiles for that play. The production history indicates that most of the conventional heavy oil wells in Western Canada produce less than 50 thousand m^3 each, over their life. However, the bulk of the production is obtained from a smaller number of more prolific wells which produce more than 50 thousand m^3 each. As expected, the low productivity wells have higher supply costs, while supply costs for the high productivity wells are relatively lower. These latter wells can be considerably more economically attractive for the operators. Most operators will have a mix of low and high productivity wells, as a normal result of exploration and development.

The Board's analysis indicates that the supply costs, in the field, range from a high of approximately $\$270/m^3$ for a well that produces 2 500 m^3 of heavy oil over its lifetime, to a low of $\$35/m^3$ for a well that produces 50 thousand m^3. For low productivity wells, a substantial reduction in supply cost is obtained as the production reaches or exceeds 10 thousand m^3. For a well that produces at least 10 thousand m^3, the supply costs average in the range of \$70 - $\$80/m^3$. For comparative purposes, the average posted price for May 2001 Bow River Heavy Blend crude oil at Hardisty, Alberta was $\$167.56/m^3$, while Lloydminster Heavy Blend at Hardisty received \$161.66. Costs of blending with diluent and cost of transportation must also be considered in making a valid comparison.

FIGURE 7.3

Upper Mannville – Well and Recovery Distributions

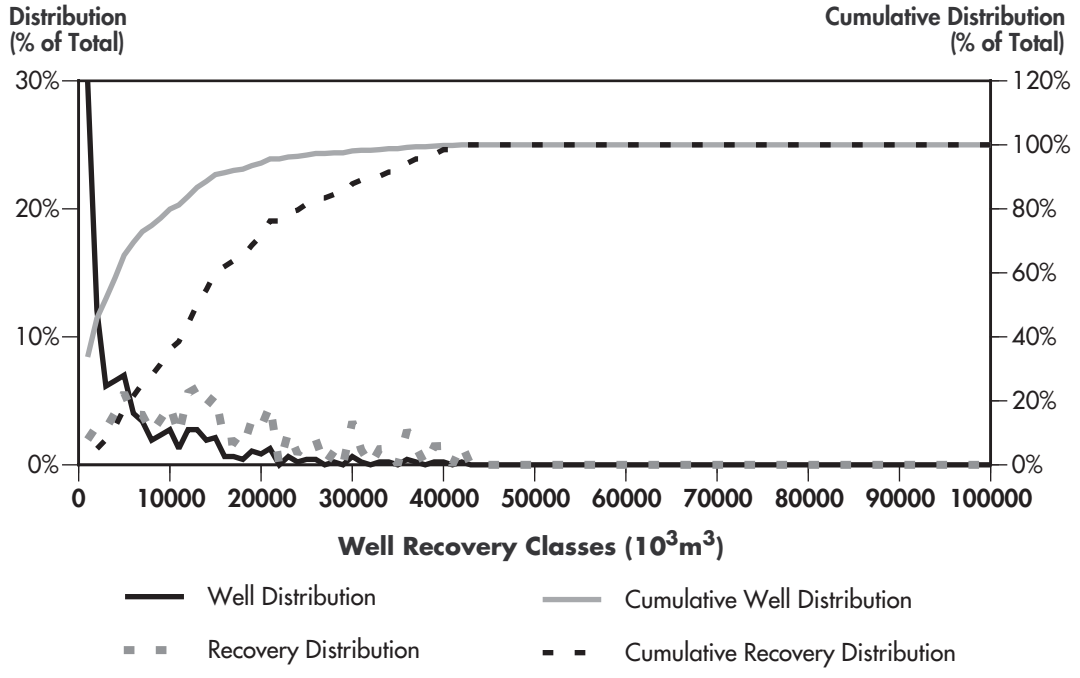
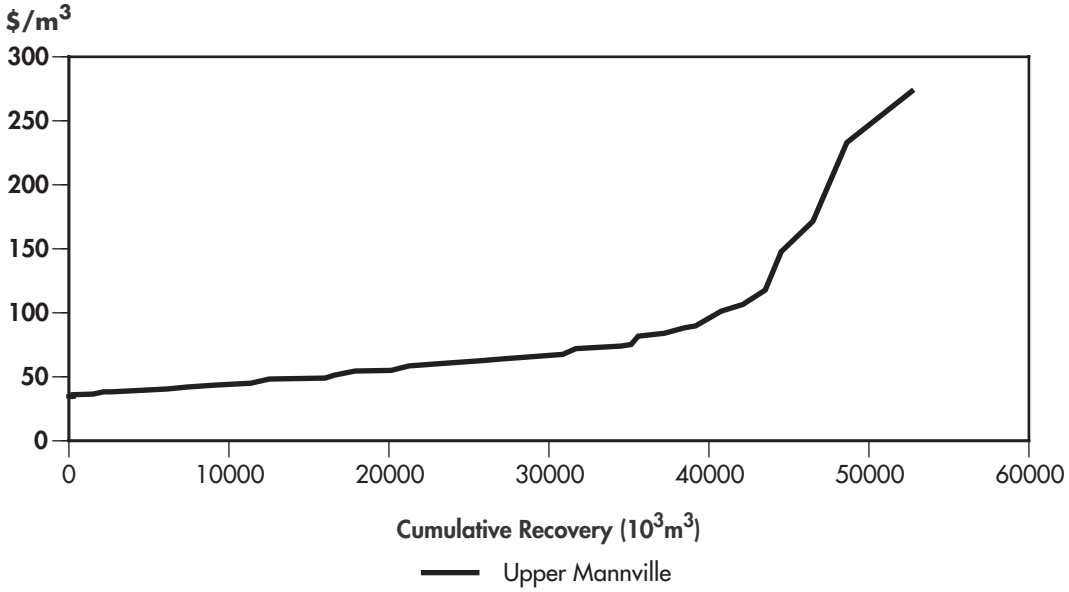


FIGURE 7.4

Supply Cost Curve – Upper Mannville



8. Other Minor Plays

The plays in this chapter contain relatively small amounts of oil in place that are characterized as heavy oil. Each play is named and defined, and the oil-in-place estimates are updated from year-end 1994 data for the discovered and undiscovered portions to year-end 1997 or 1998 depending on the province it is located. The Board did not conduct engineering or economic analyses on these plays.

8.1 Devonian Zones

8.1.1 Central Alberta Region

Leduc- Bashaw

The Leduc-Bashaw play includes oil pools within the Leduc Formation on the Bashaw reef complex, located between the Ricinus-Meadowbrook reef trend and the southern Alberta shelf. The Leduc reefs grew on the Cooking Lake Platform and are encased and sealed by the surrounding Duvernay and Ireton shales. Stratigraphic and structural-stratigraphic traps occur at the updip terminations of large reefs, downdip of re-entrants in reef complexes, and in isolated pinnacle reefs. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 4.0 million m^3 compared with 3.8 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 1.0 million m^3.

Wabamun Eroded Edge

The Wabamun Eroded Edge play is defined to include oil pools found in traps developed against the unconformity where Wabamun shelf carbonates subcrop beneath Cretaceous rocks. The play is bounded to the south by the transition to the Stettler evaporites, to the north by the Wabamun Peace River Arch play and to the west by the subcrop edge. These shallow water carbonate reservoirs commonly consist of partly dolomitized peloidal grainstones. Trapping is provided by the Cretaceous shales and by structural drape over deeper Leduc reefs. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 0.6 million m^3 compared with 0.5 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 0.4 million m^3.

8.1.2 Williston Basin Region

Leduc-Nisku Southern Alberta

The Leduc-Nisku play includes oil pools found in thick reef carbonates along the Leduc Formation barrier reef and those pools in the Camrose and Nisku carbonate shelves where they are draped over the Leduc topographical highs. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 13.5 million m^3 compared with 12.7 million m^3 at

year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 6.5 million m^3 of oil in place.

Arcs – Structural

The Arcs-Structural play includes oil pools found in structural and/or stratigraphic traps in the Arcs Member of the Nisku Formation. The Arcs is generally thin, but can reach 45 metres in thickness and consists of light coloured, fine to coarse-grained crystalline dolostone with bands of brown, granular dolomite and anhydrite. Hydrocarbons are trapped in the porous dolostones in structurally high closures which may be the result of salt solution on older Devonian evaporite sequences. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 5.3 million m^3 compared with 4.9 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 4.7 million m^3.

8.2 Triassic Zones

8.2.1 Peace River Embayment Region

Charlie Lake Carbonates

The Charlie Lake Carbonates play includes oil pools discovered in algal carbonates of the Charlie Lake Formation, in combination stratigraphic/structural traps in the area influenced by Peace River Arch/Embayment block faulting. The area is bounded by the transition to sandstone in the west and by the Charlie Lake erosional edge to the north, east and south. Pools are found in carbonate members where the principle trapping mechanism is the facies pinchout, erosional truncation and unconformity related traps. The structural component results from drape over older structures with enhanced porosity and permeability resulting from fractures. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 31.1 million m^3 compared with 27.8 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) to be 10.6 million m^3.

8.3 Jurassic Zones (First Columbian Clastic Wedge)

8.3.1 Alberta and British Columbia Region

Gilby – Medicine River Stratigraphic

The Gilby-Medicine River Stratigraphic play includes oil pools that occur in Jurassic and Lower Cretaceous sandstone, filling channels or valleys carved into the Paleozoic surface and sealed by impermeable Jurassic shales. The area is a narrow belt in south-central Alberta, trending north-northwest along the Jurassic erosional edge between Drayton Valley and Calgary. It involves a complex of erosional valleys and headlands with a variety of channel-fill units. Stratigraphically trapped pools produce oil from valley fill sands, isolated Jurassic sandstone headland remnants and sands draped over headland remnants. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 1.0 million m^3 compared with 0.9 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) to be 0.2 million m^3.

Nordegg

The Nordegg play includes oil pools that occur in Jurassic and Lower Cretaceous channel and valley fill sandstone and in Nordegg erosionally isolated shallow marine sandstones. The play

limits are the Jurassic erosional edge to the east and south, the Nordegg Platform play to the west and the Nordegg shelf/basinal play to the northwest. This play involves a complex network of Jurassic and Cretaceous erosional valleys carved into Nordegg shoreline sandstone and underlying Mississippian carbonates. The valleys are filled with Lower Jurassic to Lower Cretaceous sandstones and shales called the J_1, J_2, and J_3 units. These form stratigraphic traps that may be commingled with underlying Carboniferous pools. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 5.7 million m^3 compared with 5.4 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) to be 7.3 million m^3.

8.4 Cretaceous Zones (Second Columbian Clastic Wedge)

8.4.1 Northwest Alberta and British Columbia Region

Bluesky

The Bluesky play includes the oil pools contained within the Bluesky Formation in northwestern Alberta and northeastern British Columbia. The Bluesky Formation was deposited as a series of regressive pulses during the southward transgression of the Boreal Sea. The three main facies present are: regressive coarsening-upwards offshore to shallow marine sandstone; transgressive conglomerate lags; and, incised valley fill deposits. There has been a significant volume of heavy oil added to the discovered total as a result of Nexen's (Wascana) Hay Field development in British Columbia. That field doubled the discovered in-place oil resource estimate to 12.3 million m^3. The NEB estimated the potential heavy oil resources to be 6.8 million m^3.

8.5 Upper Cretaceous (Colorado Group) Zones (Laramide Clastic Wedge)

8.5.1 Plains Region

Viking Transgressive

The Viking Formation has been sub-divided into three plays on the basis of sequence stratigraphy as defined by Reinson et al, 1995[1]. The three plays are the Regressive, Transgressive and Channel, which occur at different stratigraphic levels. Pools from more than one play type may be present in a particular area. The Transgressive play is the only one that contains heavy oil.

The Transgressive play is defined to include oil pools in sandstones and conglomerates deposited in transgressive sequences within the upper portion of the Viking Formation. The pools are usually found in sandbar deposits or in transgressive sheet sands. Most of the heavy oil pools are found in eastern Alberta in the Vulcan, Hairy Hill and Little Bow Fields. The NEB estimated the year-end 1998 actual discovered heavy oil-in-place volume to be 2.9 million m^3 compared with 2.6 million m^3 at year-end 1994 and estimated the undiscovered potential (adjusted to year-end 1998) for heavy oil to be 1.2 million m^3.

1 Reinson, G.E., Lee, P.J., Olsen-Heise, K., Campbell, R.I., Holmstrom, G. and Gault, R.J., *Geological Play Definitions and Gas Resources, Lower Cretaceous Colorado Group, Western Canada Interior Plains* in *Proceedings of the Oil and Gas Forum 1995 - Energy From Sediments*, J.S. Bell, T.D. Bird, T.L. Hillier, and P.L. Greener (eds), GSC Open File 3058.

8.6 Summary

These plays, containing minor amounts of heavy oil, provide an additional source of conventional heavy oil supply (Table 8.1). While the heavy oil portion may not provide an identifiable exploration target, these plays have some potential in the future.

TABLE 8.1

Resources of Other Minor Plays ($10^6 m^3$)

Play	Discovered		Undiscovered
	GSC 1994	NEB 1998	NEB 1998
Leduc-Bashaw	3.8	4.0	1.0
Wabamun Eroded Edge	0.5	0.6	0.4
Leduc-Nisku Southern Alta.	12.7	13.5	6.5
Arcs-Structural	4.9	5.3	4.7
Charlie Lake Carbonates	27.8	31.1	10.6
Gilby-Medicine R. Strat.	0.9	1.0	0.2
Nordegg	5.4	5.7	7.3
Bluesky	6.2	12.3	6.8
Viking Transgressive	2.6	2.9	1.2
Total	**64.8**	**76.4**	**38.7**

9. Summary and Conclusions

During its preparation of the 1999 Supply and Demand Report, the Board relied on an assessment of conventional oil resources in the WCSB, published by the GSC in 1998, based on year-end 1994 data. At that time, the Board believed that its supply projection for conventional heavy oil was being unduly constrained by an underestimation of the size of the heavy oil resource base. Subsequently, the Board undertook to re-assess the conventional heavy oil resources in the WCSB, in preparation for the next Supply and Demand Report, targeted for release in 2003.

The Board decided to update its assessment of the discovered oil-in-place volumes of conventional heavy oil in the WCSB, to year-end 1998 (1997 for Saskatchewan), and have the GSC run the revised data in its discovery process model. The new reference dates allowed for the capture of new information from the large number of oil wells drilled in 1996 and 1997. Following the recommendation of the GSC, the Board used a different computer model, the geo-anchored method, to project the undiscovered resource base rather than using the results obtained from the PETRIMES model previously used by the GSC. This new method required the input of both the light and heavy oil-in-place data for the studied zones.

The Board's review of these resources focussed on three distinct geological zones which contain the bulk of conventional heavy oil in Western Canada: the Carboniferous; the Jurassic; and the Cretaceous. The Carboniferous zone has seven geological plays that contain heavy oil and comprise about 18 percent of the heavy oil in place. Since the last review by the GSC, the total oil-in-place volume, both light and heavy oils, for these seven plays has increased from 2 858 million m^3 to 4 211 million m^3 (18.0 to 26.5 billion barrels), with heavy oil accounting for one-third of that increased volume.

The Jurassic zone has three geological plays that contain heavy oil, comprising about 11 percent of the heavy oil in place in Western Canada. Since the last GSC review, the total oil-in-place volume, both light and heavy oils, for these three plays has increased from 533 million m^3 to 889 million m^3 (3.4 to 5.6 billion barrels), with heavy oil accounting for almost all of that increase.

The Cretaceous zone has nine geological plays that contain heavy oil, comprising almost 70 percent of the heavy oil in Western Canada. The total oil-in-place volume, for both light and heavy oils since the last review by the GSC, for these nine plays has increased from 5 408 million m^3 to 7 020 million m^3 (34.0 to 44.2 billion barrels), with heavy oil accounting for 80 percent of that increased volume.

In total, the oil-in-place volumes of light and heavy oils for all plays in the studied zones has grown from 8 798 million m^3 to 12 120 million m^3 (55.3 to 76.2 billion barrels), an increase of 38 percent. Conventional heavy oil comprises about 65 percent of the NEB's total oil-in-place volume for the studied zones. While a significant portion of the growth is due to the inclusion of the miscellaneous pool information from Saskatchewan and the Manitoba data, there has also

been growth in the existing pools and new discoveries made. There were a total of 614 new pools discovered in the studied zones between year-end 1994 and year-end 1997/98.

The Board's analysis for conventional heavy crude oil indicates that the oil in place for the studied plays has increased by about 20 percent, to 7 927 million m^3 (49.9 billion barrels), from the estimate of 6 575 million m^3 (41.4 billion barrels) provided in the Board's 1999 Supply and Demand Report. The results of the Board's new assessment are shown in Table 9.1. This increase can be attributed to the fact that this study projects the existence of a significantly greater number of smaller-sized pools compared with previous studies.

The Board's analysis of the heavy oil pools indicates that there is a significant amount of heavy oil left to be found in the studied zones in the provinces of British Columbia, Alberta and Saskatchewan. For the most part, the undiscovered pools are expected to be smaller than the discovered pools; however, there are still a few large pools projected to be found. The discovery of these large pools may require development of a new exploration strategy. As well, some of the larger pools may already be found but not yet recognized, while some of these larger pools may result from the future amalgamation of a number of smaller recognized or miscellaneous pools, after aggressive pool extension drilling.

In order to estimate the portion of the oil-in-place volumes that could be recovered, a large amount of production and performance data for heavy oil wells was analysed. Recovery factors assigned to the undiscovered pool population were based on analogy with similar sized already-discovered pools. For each zone and play, wells were grouped into respective categories, based on their estimated total recovery volumes. Typical well performance profiles, developed for these groups, were then used in determining supply costs. These supply costs estimates were subsequently used to determine the volume of economically recoverable resources.

This study estimates that 21 percent of the discovered resources, and 12 percent of currently undiscovered resources, can be technically recovered (Table 9.1). These estimates include the contributions from the application of present day, proven technology and production practices, and the potential for improved recovery through the application of future technologies. The ultimate recoverable resources of heavy conventional crude oil in Western Canada are thus estimated to be some 1 391 million m^3 (8.8 billion barrels), an increase of 8.5 percent compared with the Board's 1999 Supply and Demand Report.

Supply cost curves were generated for each geological play, and, in general, the Jurassic plays have the lowest costs while the Cretaceous plays have the highest. Among individual plays, the Jurassic Shaunavon play has the lowest mean supply cost at \$38/m^3 (\$6.04/bbl) and the Carboniferous Souris-Tilston play has the highest at \$125/m^3 (\$19.87/bbl). A review of supply costs considered in aggregate, suggests that 65 percent of the technically recoverable volume can be recovered economically at a price point of \$62.38/m^3 (\$9.91/bbl) in the field, or 80 percent at \$83.91/m^3 (\$13.02/bbl).

Considering these supply costs in relation to recent prices for heavy crude oil, with May 2001 Bow River Heavy Blend crude oil at Hardisty, Alberta posted at \$167.56/m^3 (\$26.64/bbl), and Lloydminster Heavy Blend at Hardisty at \$161.66/m^3 (\$25.70/bbl), heavy crude production would seem relatively attractive for most plays. Costs of blending with diluent and cost of transportation must also be considered.

This assessment of heavy oil resources, given the test of time, will likely prove to be somewhat conservative. Past experience suggests this will be the case, perhaps due to the inherent

conservative nature of resource estimation by statistical analysis. More specifically, the Board acknowledges that its own process for the largest conventional heavy oil play, the Cretaceous Colony to Lloydminster play, results in a more conservative estimate. Grouping seven horizons that could potentially be assessed as seven separate plays into one play results in a lower overall assessment.

TABLE 9.1

Summary of All Zones, Heavy Oil Only

Metric ($10^6 m^3$)

Zone	Oil In Place		Recoverable			
	Discovered	Undiscovered	Discovered			Undiscovered
			Established Reserves	Remaining Reserves	Future Improved Recovery [1]	Undiscovered Recoverable [1]
Carboniferous	801.7	612.2	108.1	33.8	53.2	82.8
Jurassic	545.1	336.2	149.9	28.6	28.6	50.7
Cretaceous	3 608.6	1 907.7	422.3	126.8	291.0	204.3
Other	76.4	38.7	n/a	n/a	n/a	n/a
Total	5 031.8	2 894.8	680.3	189.2	372.8	337.8
	Total Oil In Place = 7 926.6		Total Recoverable = 1 390.9			

Imperial - (million barrels)

Zone	Oil In Place		Recoverable			
	Discovered	Undiscovered	Discovered			Undiscovered
			Established Reserves	Remaining Reserves	Future Improved Recovery [1]	Undiscovered Recoverable [1]
Carboniferous	5,042	3,850	680	213	335	521
Jurassic	3,428	2,114	943	180	180	319
Cretaceous	22,665	11,982	2,656	797	1,830	1,285
Other	481	243	n/a	n/a	n/a	n/a
Total	31,616	18,189	4,279	1,190	2,345	2,125
	Total Oil In Place = 49,805		Total Recoverable = 8,749			

[1] Both components of future improved recovery are included (ie. that from current technology and optimization plus that from the implementation of future technologies) for both discovered and undiscovered pools.


Canada