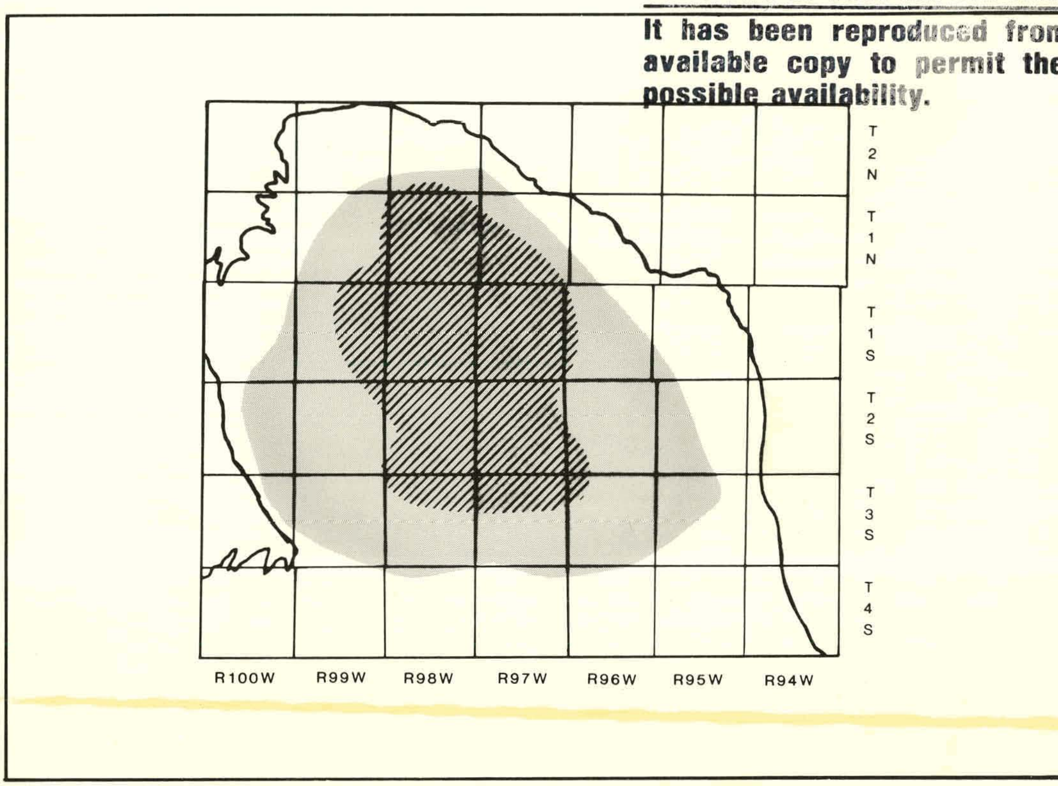
DOE/RA/34014--T2

MARKET ANALYSIS OF SHALE OIL CO-PRODUCTS



SUMMARY REPORT

PREPARED BY

LEWIN & ASSOCIATES, INC.

E.G. HIGGINS FEDERAL, INC.

ENERGY DEVELOPMENT CONSULTANTS, INC.

PREPARED FOR
U.S. DEPARTMENT OF ENERGY
RESOURCE APPLICATIONS

DECEMBER, 1980

DISCLAIMER

DOE/RA/34014--T2

MARKET ANA YSIS OF

SHALE OIL CO-PRODUCTS

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DE82 011715

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RESOURCE APPLICATIONS

OFFICE OF OIL SHALE RESOURCE APPLICATIONS

UNDER CONTRACT NO. DE-AC01-79RA 34014

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- Lewin and Associates, Inc.
  Mr. Vello A. Kuuskraa
  Mr. Edgar C. Hammershaimb

- E. G. Higgins Federal, Inc.
  Mr. E. G. Higgins

- Energy Development Consultants, Inc.
  Mr. R. Trent
  Mr. J. Broz

Beyond these individuals, the study staff acknowledges the valuable contributions and efforts of other members of the staff in all three companies to the technical and clerical support of this study.

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EXECUTIVE SUMMARY

This study examines the potential for separating, upgrading and marketing sodium mineral co-products together with shale oil production. The co-products investigated are soda ash and alumina which are derived from the minerals nahcolite and dawsonite.

Five cases, shown on Exhibit 1, were selected to reflect the variance in mineral and shale oil content in the identified resource. The thickest deposits of nahcolite and dawsonite generally coincide with the center of the shale oil deposits in the northern Piceance Creek Basin. In the rich mineral areas, the nahcolite content is 20% by weight and the dawsonite content is 12% by weight. At the periphery of the deposit, the dawsonite content drops to 2% by weight and nahcolite is no longer present. In the five cases examined, oil content of the shale was varied from 20 to 30 gallons per ton. Two sizes of facilities were analyzed for each resource case to determine economies of scale between a 15,000 barrel per day demonstration unit and a 50,000 barrel per day full sized plant.

Three separate pieces of analysis were conducted in this study:

- Analysis of manufacturing costs for shale oil and co-products. Detailed process flow diagrams and energy and mass balances were developed for each of the key mining and manufacturing steps; these formed the basis for engineering estimates of capital and operating costs.

Exhibit 1

PRODUCT SLATES FOR THE FIVE CASES

Raw Material	Case 1	Case 2
Lean Minerals Rich Shale	Shale: 21,053 TPD Oil: 13,571 BPD Nahcolite: -- Alumina: 75 TPD Soda ash: 78 TPD (1 retort module)	Shale: 84,212 TPD Oil: 54,284 BPD Nahcolite: -- Alumina: 300 TPD Soda ash: 312 TPD (4 retort modules)
Rich Minerals Rich Shale	**Case 3** Shale: 25,316 TPD Oil: 15,639 BPD Nahcolite: 4,050 TPD Alumina: 523 TPD Soda ash: 991 TPD (1 retort module)	**Case 4** Shale: 75,948 TPD Oil: 46,917 BPD Nahcolite: 12,150 TPD Alumina: 1,569 TPD Soda ash: 2,973 TPD (3 retort modules)
Rich Minerals Lean Shale	Not analyzed	**Case 5** Shale: 126,582 TPD Oil: 52,132 BPD Nahcolite: 20,253 TPD Alumina: 2,616 TPD Soda ash: 4,956 TPD (5 retort modules)

- Projection of potential world markets for alumina, soda ash and nahcolite. Future market demand and prices for alumina, soda ash and nahcolite were projected by major geographical areas and major end uses for each of the co-products, as well as for the competing sources of supply.

- Determination of economic viability and market potential for shale co-products. Finally, the cost analysis was integrated with the market study to determine the locations, conditions, prices, and magnitude of co-product markets.

The economic analysis was completed assuming a 2% annual increase in energy prices and no upgrading (hydrotreating) of the shale oil. Based on current market prices, raw shale oil is assumed to require a manufacturing cost of $25 per barrel or less to be economic.

The major findings for the integrated shale oil and co-product plant are as follows:

- For the "rich shale, rich minerals" resource, the recovery of mineral co-products can make an otherwise uneconomic shale oil demonstration plant of 15,000 barrels per day economically feasible. The manufacturing costs for shale oil would be uneconomic at $29.20 per barrel (including a 15% ROR) but, sufficient additional revenue could be generated by the co-products to make the total facility economic. The full size commercial shale oil plant of 50,000 barrels per day is economic without co-product credits, although these would further improve the economics.

- For the "lean shale, rich minerals" resource, the commercial recovery of mineral co-products can make an otherwise uneconomic full-scale, 50,000 barrels per day plant economic, assuming current world oil prices and real price escalation of 2% per year for energy. While the shale oil component of the plant does not meet the 15% return on investment criteria, the attractive profit margins of the mineral co-products could make the integrated facility an economically viable venture. This is a most important finding, as the co-production of alumina and soda ash appear able to make lower grade oil shale, of 20 gallons per ton, economically viable.

- In the "lean minerals" areas, the manufacturing costs of the co-products are too high, even under marginal costing, to be economically viable.

The main findings for alumina are:

- The major markets for co-product alumina include displacing current alumina imports, replacing outmoded domestic plants and providing raw material for increased aluminum production in the U.S. and Canada. These markets are estimated at 6 to 11 million tons annually by the year 2000. The market price for alumina by the year 2000 is estimated to range from $240 to $280 per ton (in 1980 $), based on domestic upgrading (with the Bayer Process) of imported bauxite:

Year	Anticipated Demand Million Tons/Year	Anticipated Price $/Ton, 1980 $
1990	3-5	230 - 270
2000	6-11	240 - 280
2010	9-16	250 - 290

- Co-product alumina is found to cost $257 per ton in 1990, including $35 per ton in offgas costs. Because escalating energy costs are already included, co-product alumina costs will not increase, in real 1980 dollars, while competitive products will increase in price, as shown above. Thus, it appears likely that the recovery of alumina from dawsonite associated with shale will be economically feasible and that this product can penetrate the market.

- Included in the imputed market price of competitive alumina is $50 per ton of Jamaican taxes. However, even if Jamaica alters its tax structure, the direct operating costs of shale co-product alumina will be lower than the upgrading of bauxite to alumina, once the plants have been built. Thus major price cuts by bauxite exporting countries would not displace existing domestic shale co-product alumina plants.

- Domestic production of alumina provides a secure source of an important strategic raw material. Additional benefits include an improved balance of payments, up to approximately 1 billion dollars a year, and a backstop price to help brake future increases in bauxite pricing by the IBA cartel.

The main findings for soda ash are:

- Except in the U.S and Africa, soda ash is produced by the Solvay process which is highly energy intensive, and whose manufacturing costs are about twice those of shale co-product soda ash. In the U.S., soda ash is produced by the mining and upgrading of trona at a cost estimated to be competitive with co-product soda ash.

- Expected real increases in energy prices will increasingly favor the economics of U.S. soda ash. The cost of co-product soda ash is found to be $77 per ton in 1980, including $40 per ton for offgas costs. The equivalent landed cost in Western Europe and Japan, of about $140 per ton, is competitive with current market prices. The major future markets for soda ash are from growth in West European or Asian demand for sodium oxide and the replacement of West European and the deplacement of East European Solvay based soda ash. Other major markets include: product substitution if chlorine demand (with its caustic soda production) remains stable or declines, growth in domestic demand for sodium oxide, and new markets for soda ash.

- The overall market potential for co-product soda ash and the market price of competitive sources is estimated as shown below (the domestic price is related to trona mining and the international price to the cost of Solvay based soda ash):

Year	Anticipated Market, Million Tons/Year	Anticipated Price $/Ton, 1980 $	
		Domestic	International
1990	4 - 5	50 - 90	150 - 210
2000	9 - 12	60 - 100	170 - 230
2010	14 - 18	70 - 110	200 - 260

- The anticipated market of 9 to 12 million tons per year in the year 2000 assumes that co-product soda ash and U.S. trona manufacturers share new sodium oxide markets and that Western Europe and Japan do not erect trade barriers against U.S. produced soda ash.

The major findings for nahcolite are:

- Although nahcolite could be produced at very low marginal manufacturing costs, transportation costs are significant and place severe geographic limits on the potential market.

- The major, anticipated market is stack gas scrubbing. However, given the current leveling of electricity demand, changes in government regulations, and rapid developments in scrubbing technology, any market projections are uncertain.

- Overall, the market for nahcolite in 1990 could be up to one million tons per year. This is equivalent to the output of a single 15,000 barrel per day demonstration unit. It therefore appears likely that the bulk of the nahcolite recovered as part of shale oil mining will be backfilled in the mine.

Converting the market potential from tons of minerals to barrels of shale oil shows that these markets would support a shale oil industry equal to 500,000 barrels per day in the year 2000 and 800,000 barrels per day by 2010, with an upside potential of 1,250,000 barrels per day by 2010, as shown below in thousands of barrels per day, by co-product:

Year	Demand for Co-Product Alumina (MB/D)	Demand for Co-Product Soda Ash (MB/D)	Most Likely Capacity (MB/D)
1990	230-400	170-220	250
2000	450-850	400-500	500
2010	700-1,250	600-800	800

In summary, co-product minerals could make an important economic contribution to a shale oil industry. The major market limit could be set by alumina, since the marginal costs of producing soda ash might be as low as $10 to $30 per ton and might readily vie with trona mining for a larger share of the future growth in sodium oxide markets.

CHAPTER I

POTENTIAL OF SHALE CO-PRODUCTS

Introduction

This report discusses the feasibility for economically extracting, upgrading and marketing minerals that occur with oil shale. The study was conducted by Lewin & Associates, Inc., who directed the work and performed the economic and integrating analyses; Energy Development Consultants, Inc., who performed the mining and upgrading analysis; and, E. G. Higgins, Federal, who performed the marketing study.

Purpose

The purpose of this study is to analyze the potential for economically recovering and marketing co-product[1] minerals associated with shale oil to determine whether they might improve the economics of shale oil production.

Recently, an increasing amount of attention has been directed toward the large shale oil resource in Colorado. Several studies have been undertaken to analyze the technical and economic feasibility of extracting this oil, most recently by the Office of Technology Assessment. In general, these studies have concluded that the technology could be developed but that the economics would be marginal.

Associated with the oil shale in some deposits in Colorado are sodium minerals, in particular nahcolite and dawsonite. The first mineral is a natural sodium bicarbonate ash and the second is a chemical composition of sodium and aluminum. Thus, dawsonite can be upgraded to yield alumina, the precursor of aluminum, with soda ash as a by-product. Since these minerals are interspersed with oil shale, mining of the latter would also entail mining of the former. Should it be economically feasible to upgrade and market these minerals as co-products, the economics of shale oil recovery might be improved.

The Resource

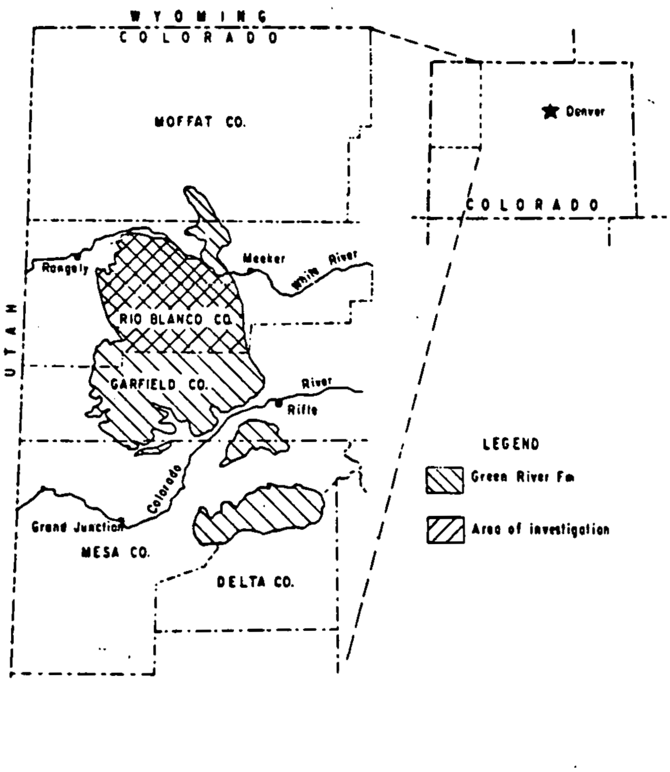
Major deposits of oil shale occur in the Green River Formation of the Piceance Creek Basin in Northwestern Colorado, Exhibit 1-1. The northern half of the Basin also contains vast deposits of nahcolite ($NaHCO_3$) and dawsonite ($NaAl(OH)_2CO_3$), that are co-deposited with the shale in the Saline Zone which underlies the Leached Zone. Exhibit 1-2 shows a cross-section of the Piceance Basin and the deposition of minerals in the Saline Zone.

Data on 22 cores from the Saline Zone have been reported by T.N. Beard, D.B. Tait and J.W. Smith in 1974 (Nahcolite and Dawsonite Resources in the Green River Formation, Piceance Creek Basin, Colorado). The location of these cores is shown on Exhibit 1-3. From this and other data, estimates of the nahcolite and dawsonite resources have been developed as shown on Exhibits 1-4 and 1-5, respectively. The northern area of the Piceance Creek Basin generally coincides with the occurence of the two minerals, although the dawsonite deposits extend further east than those of nahcolite. The center and thickest deposits of both minerals occur in Township 1 South, Range 98 West. The in-place nahcolite resource is estimated to be about 30 billion tons; the dawsonite resource is estimated to represent 6 to 7 billion tons of alumina.

The core data indicates that the areas with the largest mineral content (T1S, R98W) contain ore with about 20% nahcolite and 12% dawsonite by weight. Along the edge of the basin in the areas

Exhibit 1-1

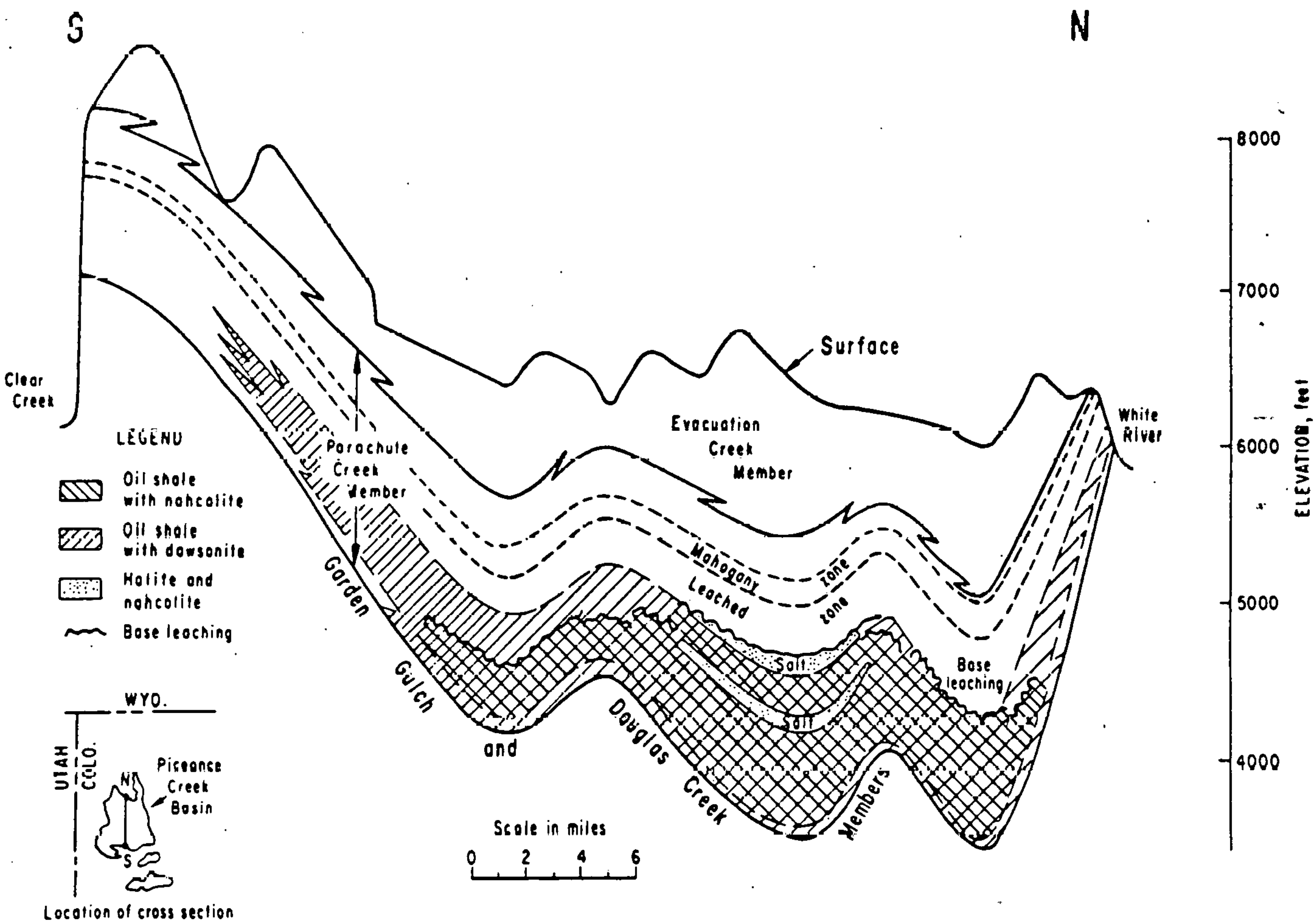
INDEX MAP, PICEANCE CREEK BASIN, COLORADO



Source: Nahcolite and Dawsonite in Green River Formation, Colorado; T.N. Beard, D.B. Tait, and J.W. Smith

Exhibit 1-2

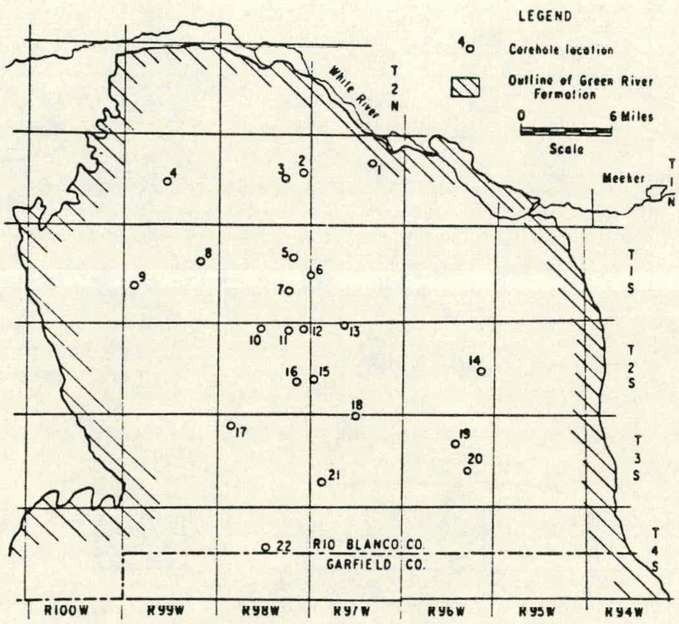
CROSS-SECTION OF THE PICEANCE CREEK BASIN



Source: Nahcolite and Dawsonite in Green River Formation, Colorado; T.N. Beard, D.B. Tait, and J.W. Smith

Exhibit 1-3

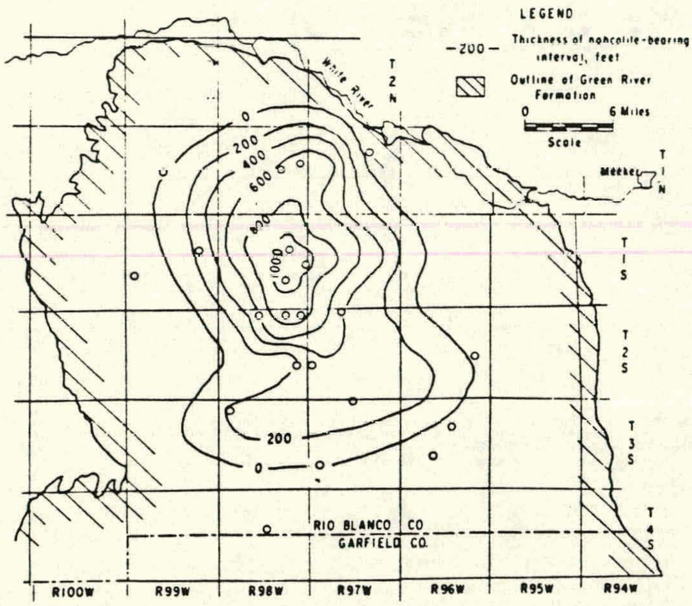
CORES THROUGH THE SALINE ZONE



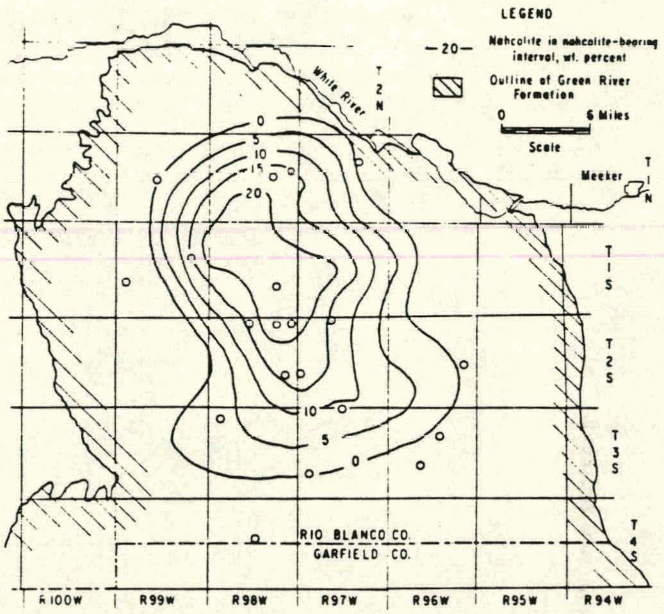
Source: Nahcolite and Dawsonite in Green River Formation, Colorado; T.N. Beard, D.B. Tait, and J.W. Smith

Exhibit 1-4

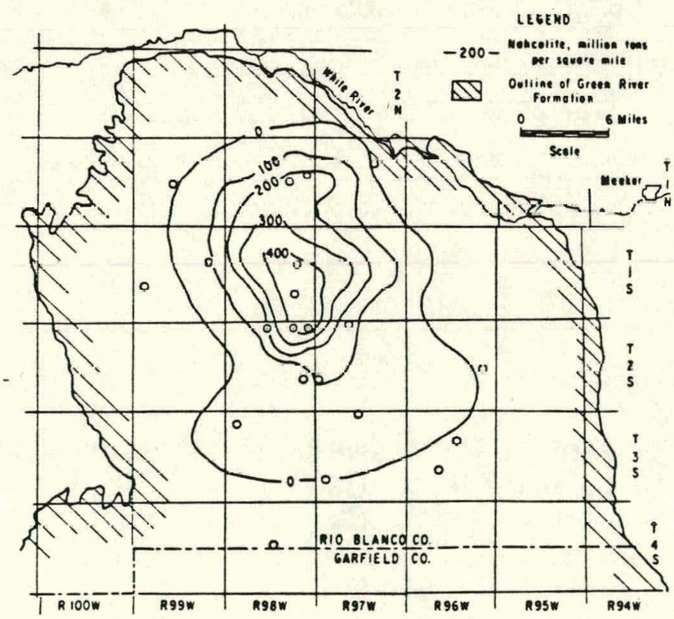
NAHCOLITE RESOURCE DISTRIBUTION



Thickness of nahcolite-bearing interval, Green River Formation, northern Piceance Creek basin, Colo.



Nahcolite content of nahcolite-bearing interval, in average weight-percent.

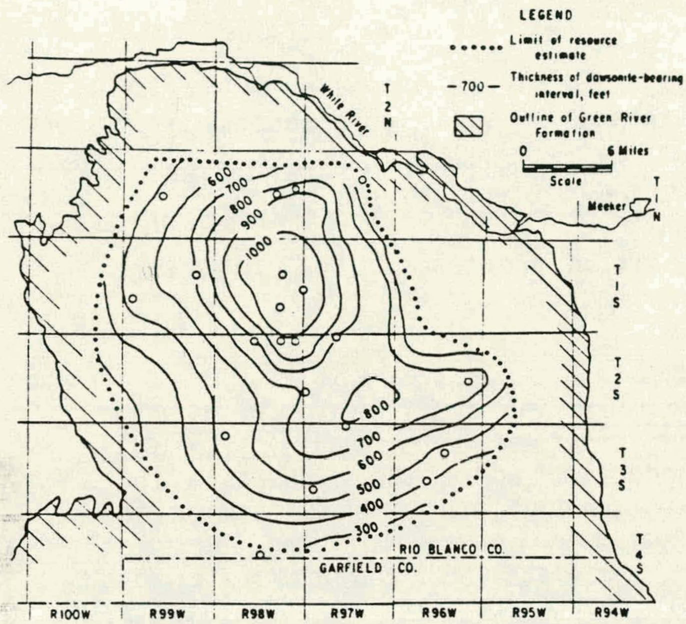


Nahcolite isoreserves in nahcolite-bearing interval, in millions of tons per sq mi.

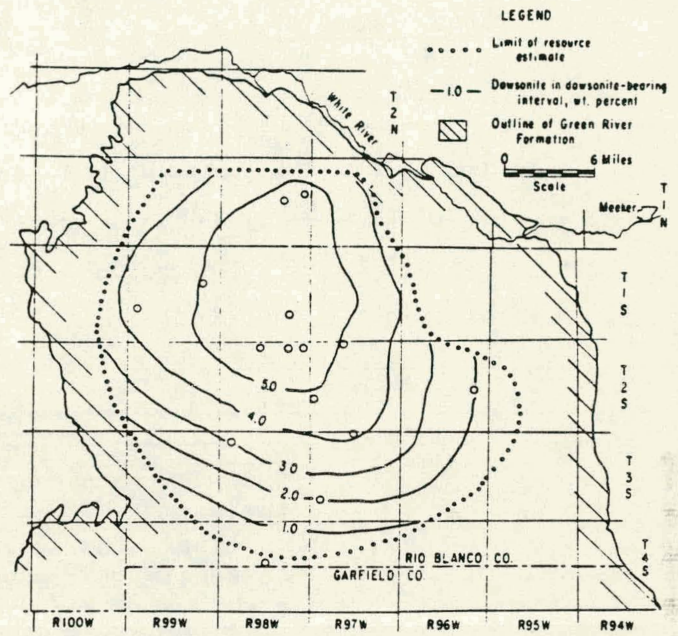
Source: Nahcolite and Dawsonite in Green River Formation, Colorado; T.N. Beard, D.B. Tait, and J.W. Smith

Exhibit 1-5

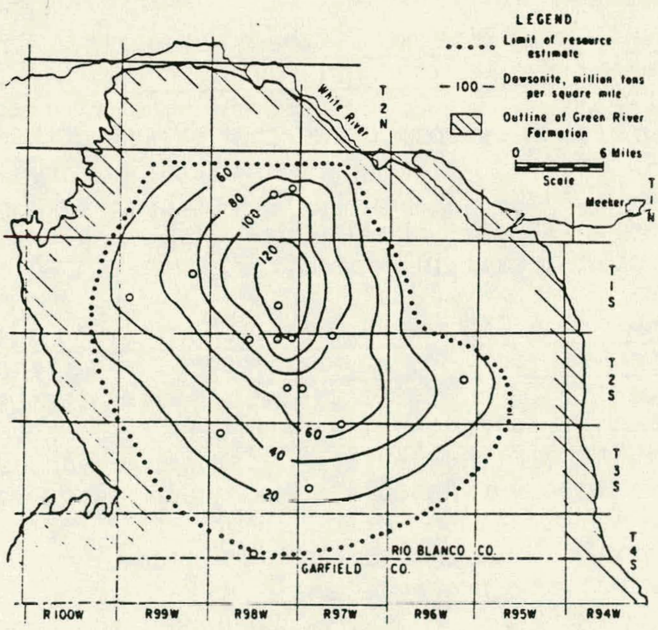
DAWSONITE RESOURCE DISTRIBUTION



Thickness of dawsonite-bearing interval, Green River Formation, Colo.



Dawsonite content of dawsonite-bearing interval, in weight-percent.



Dawsonite isoreserves in dawsonite-bearing interval, in millions of tons per sq mi.

Source: Nahcolite and Dawsonite in Green River Formation, Colorado; T.N. Beard, D.B. Tait, and J.W. Smith

where there is no nahcolite, the dawsonite content is about 2% by weight. The average oil content of the shale in this area is estimated to range from 20 to 30 gallons per ton.

Study Approach

To analyze the market potential of shale co-products, it is necessary to determine the economics of upgrading the minerals and to estimate the potential market for these products at a market price that is based on the costs of competitive processes. For this, three tasks were conducted:

- Task 1. Determine manufacturing costs of shale oil and co-products. The first task was to establish the full costs of shale oil production under the assumption that shale oil is the primary product, and then determine the marginal costs of separating nahcolite and upgrading dawsonite to commercial grade soda ash and alumina. This task was performed by Energy Development Consultants, Inc. (EDC) and Lewin and Associates (Lewin). It is summarized in Chapters 2 and 3, and is discussed in greater detail in Appendices 1 and 2 of this report.

- Task 2. Determine the potential world market for alumina, soda ash and nahcolite. The second, parallel task was to determine the market demand, competing sources of supply, and the market price for the shale co-products by major geographical area and major end use. This task was performed by E. G. Higgins, Federal (EGH). It is summarized in Chapter 4 and is discussed in greater detail in Appendix 3.

- Task 3. Estimate the economic viability and market potential for shale co-products. The final task was to integrate the cost analysis with the market study to determine under what conditions, at what prices, and to what extent the shale oil derived co-products -- alumina, soda ash and nahcolite -- could penetrate domestic and export markets. In addition, this task determined the economic impact of co-product recovery on the recovery of the primary product, shale oil. This task was performed by Lewin and EGH, and is discussed in Chapters I and IV.

Fundamental Study Assumptions

The economics of shale co-products depend greatly on the distribution and richness of shale oil and co-product minerals as well as the scale of operation. To reflect these conditions, five illustrative cases, as defined below, were created and analyzed in detail:

	Plant Size: Single Unit	Plant Size: Full Scale Plant
Lean Minerals, Rich Shale - 0% Nahcolite - 2% Dawsonite - 30 Gallon per ton shale	Case 1	Case 2
Rich Minerals, Rich Shale - 20% Nahcolite - 12% Dawsonite - 30 Gallon per ton shale	Case 3	Case 4
Rich Minerals, Lean Shale - 20% Nahcolite - 12% Dawsonite - 20 Gallon per ton shale	--	Case 5

The Single Unit is a pilot plant of about 15,000 barrels per day, while the Full Scale Plant is a commercial unit of about 50,000 barrels per day. Besides addressing the larger marketing volumes produced by the Full Scale Plant, the analysis of two plant sizes identifies any economies of scale.

Case 3 can be considered the Base Case since it is a pilot plant in the rich minerals, rich shale portion of the Basin and therefore reflects the most probable initial development project.

Product Slate

Retorts for shale oil processing are designed for a charge of 20,000 tons of ore per day and cannot easily be scaled to other sizes. In addition, for technical reasons, the retorts must operate at a minimum of 95% of full capacity. Since the retort determines the production, the actual tonnage mined and thus oil produced in the five cases varied from the nominal 15,000 and 50,000 barrels per day as shown on Exhibit 1-6, depending on the mineral content of the mined shale.

The product slates for each of the five cases is also shown on Exhibit 1-6. Cases 1 and 2, representing the "lean minerals" case, have a low dawsonite content and no nahcolite, and consequently the production of alumina and soda ash is small. In Case 4, the Full Scale Plant, "rich minerals" case, the soda ash produced together with alumina is 1,000,000 tons per year, equivalent to a world-scale soda ash plant. The alumina production in Case 4 corresponds to an annual production of 570,000 tons of alumina, which would be about 6% of total 1980 U.S. consumption. In Case 5, where the oil content of the shale is lower (at 20 gallons per ton), five retorts are required to produce about 50,000 barrels of oil per day. The resulting annual production of 1.8 million tons of soda ash would be a major addition to world capacity. The alumina production of nearly 1 million tons per year would be about 10% of U.S. consumption.

Exhibit 1-6

PRODUCT SLATES FOR THE FIVE CASES

Raw Material	Case 1	Case 2
Lean Minerals Rich Shale	Shale: 21,053 TPD Oil: 13,571 BPD Nahcolite: -- Alumina: 75 TPD Soda ash: 78 TPD (1 retort module)	Shale: 84,212 TPD Oil: 54,284 BPD Nahcolite: -- Alumina: 300 TPD Soda ash: 312 TPD (4 retort modules)
	Case 3	Case 4
Rich Minerals Rich Shale	Shale: 25,316 TPD Oil: 15,639 BPD Nahcolite: 4,050 TPD Alumina: 523 TPD Soda ash: 991 TPD (1 retort module)	Shale: 75,948 TPD Oil: 46,917 BPD Nahcolite: 12,150 TPD Alumina: 1,569 TPD Soda ash: 2,973 TPD (3 retort modules)
		Case 5
Rich Minerals Lean Shale	Not analyzed	Shale: 126,582 TPD Oil: 52,132 BPD Nahcolite: 20,253 TPD Alumina: 2,616 TPD Soda ash: 4,956 TPD (5 retort modules)

Market Potential

The analysis shows that while the costs of shale oil are competitive in Cases 1 and 2, the costs of alumina and soda ash are not because of the low mineral content of the mined shale. Case 5 has the shale with lowest oil content and thus, in general, the shale oil economics are the worst of the five cases, but not significantly so because of the credits available from the mineral co-products which are mined in large quantities. However, these large volumes would also significantly reduce the size of an oil shale industry supported by mineral co-production.

The following discussion focuses on Case 3 since this can be considered the Base Case, and the assumed resource characterizes a large portion of the resource.

The economic analysis shows that the cost of alumina and soda ash can be broken down as follows:

	Alumina, $/Ton	Soda Ash, $/Ton
Direct Operating Costs	131	22
Offgas Costs	35	40
Other	91	15
Total	257	77

The retort produces low BTU offgas. Although this gas may not have an alternative use, it was assumed that this offgas would be used in the manufacture of alumina and soda ash at a cost of $5 per million BTU.

These alumina and soda ash costs reflect a 2% per year escalation in energy costs and would remain constant in real terms over the life over the shale oil plant. These costs are also FOB works and thus do not include transportation.

1. Alumina Markets

Delivered alumina costs are highly dependent on transportation costs and the majority of alumina and aluminum plants are located near water to use this cheaper transportation mode. A shale oil co-product facility would need to use rail freight and would, moreover, have to build a railroad spur to the plant. Transportation costs are therefore difficult to determine, particularly since railroad rates are being decontrolled. Because of its geographic location, a shale oil plant might have competitive transportation economics with the movement of alumina from the Gulf Coast to the Northwest smelters, but this study assumes that shale co-product alumina has no transportation advantages or disadvantages relative to other sources of alumina.

The market analyses conclude that in 1990 the potential co-product alumina market in the U.S. and Canada is 3 to 5 million tons per year, with alumina from competitive processes priced at $230 to $270 per ton. These costs include about $50 per ton Jamaican taxes and they escalate with energy costs, so that by the year 2000 the costs range from $240 to $280 per ton. The market for co-product alumina and the cost of competitive production is summarized below:

	Million Tons/Year	$/Ton, 1980 $
1990	3-5	$230 - $270
2000	6-11	$240 - $280
2010	9-16	$250 - $290

Co-product alumina thus appears sufficiently economic to capture the total potential market (particularly if offgas costs are reduced) with a 15% Return on Investment and to assist the shale oil economics by "purchasing" offgas from the retort. The shale oil capacity that these alumina markets would support are:

Year	MBPD
1990	230 - 400
2000	450 - 850
2010	700 - 1,250

Moreover, the direct operating costs of co-product alumina are lower than those of competing processes. Even if Jamaica amended its tax structure and U.S. tariffs were not reimposed, any existing co-product facilities might still be economic.

2. Soda Ash Markets

Transportation costs are more important for soda ash markets than for alumina, since they constitute a larger percentage of total costs. Currently, rail transportation charges from the Green River Basin to the U.S. Gulf Coast or West Coast are about $42 per ton. Ocean freight to Western Europe or Asia would add another $20 per ton to transportation costs. Assuming transportation costs increase 1% per year, the landed costs of co-product soda ash are projected to be:

	Dollars per Ton			
	1980	1990	2000	2010
Soda Ash, CIF	139	145	152	160

The market potential for co-product soda ash and international costs of competing processes are estimated as follows:

Year	Million Tons/Year	Market Price, $/Ton
1990	4-5	150-210
2000	9-12	170-230
2010	14-18	200-260

The low range of this potential market assumes that co-product soda ash will displace existing West European Solvay plants by 2010 and capture 50% of West European and Asian growth markets. The high side assumes additionally that some sales to Western Europe of East European Solvay ash will be displaced, that some U.S. growth markets will be covered by co-product soda ash, that soda ash will replace some caustic soda, and that new markets will develop.

The 1990 delivered costs of co-product soda ash are below the range of the estimated competitive market price. Thus, it appears that the full market potential of 4 to 5 million tons could be achieved. However, even half of this market would be larger than the capacity that could be expected to be installed by 1990, since each 50,000 barrel per day shale oil plant produces 1 million tons of soda ash annually in the rich minerals, rich shale cases.

About 60% of the costs for Solvay soda ash consist of energy costs. Thus, the inherent cost structure is such that Solvay ash will become increasingly more costly while co-product soda ash will only escalate with transportation costs -- assuming no protective tariffs are imposed.

The potential soda ash markets correspond to the following shale oil production:

Year	Soda Ash Production, MM Tons/Year	Shale Oil Production, MBPD
1990	4-5	170 - 220
2000	9-12	400 - 500
2010	14-18	600 - 800

3. Interrelation of Alumina and Soda Ash Markets to Shale Oil Production.

Although alumina and soda ash world markets may be independent of each other, the production of soda ash is dependent on alumina production which, in turn, depends on oil production.

The major market limit appears to be for alumina, since the marginal costs of producing soda ash could be as low as $10 to $30 per ton and could readily vie for a larger share of the growth in the sodium oxide market. Converting the market potential from tons of minerals to barrels of shale oil shows that these markets would readily support an industry equal to 500,000 barrels per day shale oil capacity in the year 2000, and 800,000 barrels per day by 2010, with an upside potential of 1,250,000 barrels per day by 2010, as shown below by product:

Year	Range of Market Demand for Co-Product Alumina	Range of Market Demand for Co-Product Soda Ash	Most Likely Capacity
1990	230-400	170-220	250*
2000	450-850	400-500	500
2010	700-1,250	600-800	800

*Implies that soda ash would need to capture more than a 50% market share of growth in sodium oxide demand, with trona capturing the remainder.

A major intangible in assessing the market potential of alumina and soda ash is that the shale oil co-products would be produced and made available outside traditional channels. This could require shale oil producers to develop innovative marketing schemes or to cooperate with existing manufacturers, domestic or foreign, to use existing marketing channels.

CHAPTER II

MINING, SEPARATION AND UPGRADING

Introduction

To determine co-product availability and economics, the following analyses were conducted for each of the five cases:

- Preliminary engineering design of mineral co-product facilities,
- Full cost-engineering and economic analysis of the shale oil plant, and;
- Marginal (capital and operating) cost analysis for co-product facilities.

To complete this study, it was first necessary to develop a detailed conceptual analysis of the processes by which the minerals would be separated or upgraded. One above-surface commercial venture has been proposed for mineral recovery in combination with processing of shale for oil production, but inadequate details were available to construct the required process, calculate mass and energy flow diagrams, and determine capital and operating costs.

Process Flow

After mining, the material is assumed to be transported to the surface for primary crushing. Next, the nahcolite is separated through further crushing and photosorting and the non-nahcolitic shale charged to the retort. This process flow is shown diagrammatically on Exhibit 2-1, where the mass flow for Case 3 is also indicated.

The following assumptions were made for the mine design:

- Co-product Determined Factors:

  -- Single level, room and pillar mine in the Saline Zone. Based on existing plans for shale mines and the experience of the design team, this mining method would be the most appropriate at the depth of about 2,000 feet under the surface, the depth of the Saline Zone in the areas of the chosen cases.

  -- A uniform, flat-lying bed of oil shale with dawsonite and inter-bedded nahcolite nodules and a mineable thickness of 60 feet. Since the purpose of the study was to evaluate the potential of co-products, no selective mining of extended nahcolite lenses was assumed. The thickness of 60 feet was chosen, based on core data and conservative estimates of the technically feasible mine size.

- Conventional Mining Factors:

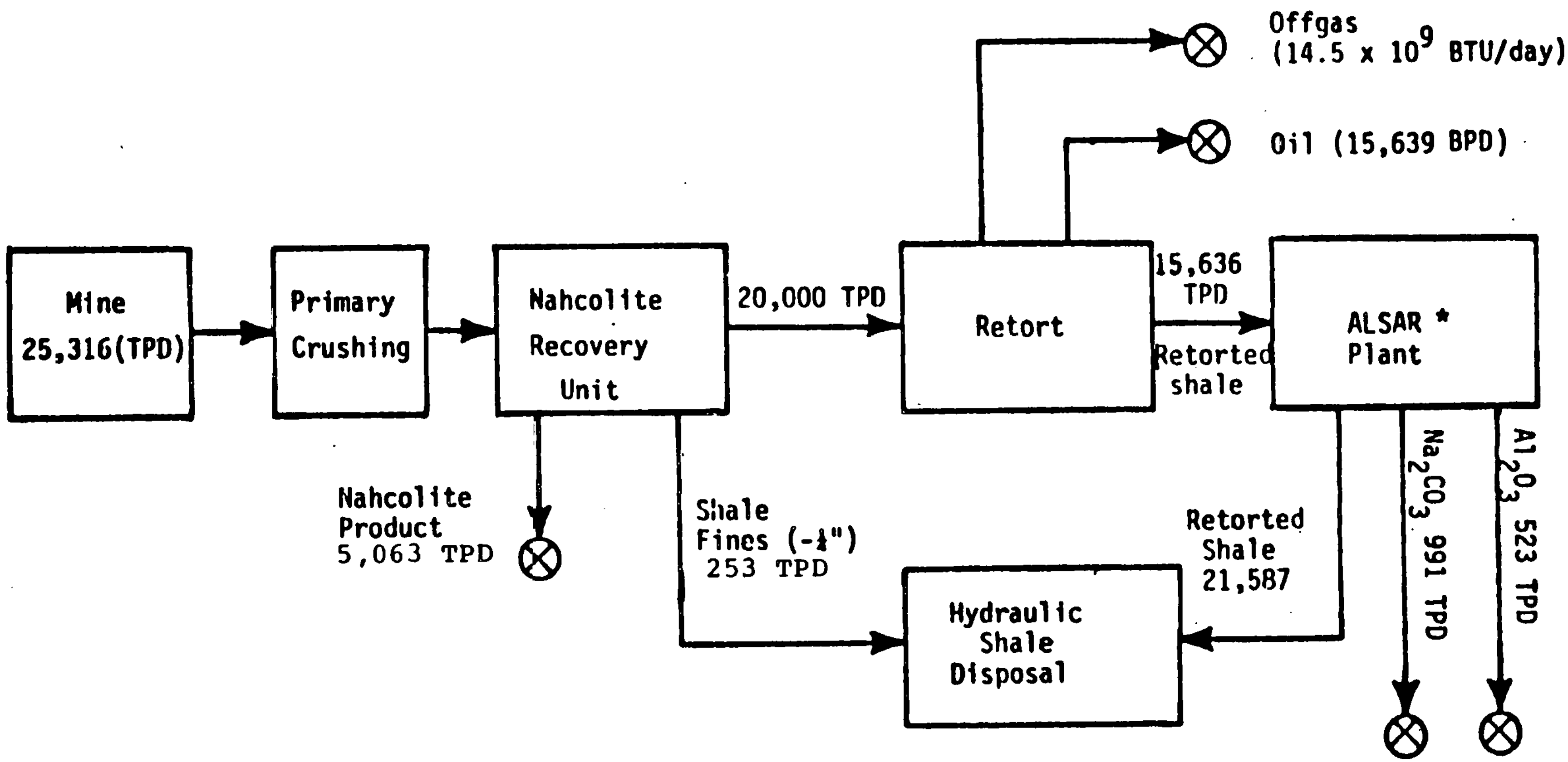
  -- The mine is developed in panels approximately 6,000 feet long and 1,100 feet wide.

  -- Pillars are a minimum of 120 feet laterally and mining is limited to an overall extraction of 45 percent. This pillar size is based on extrapolation of previous experience, taking into account the presumed competency of the formation.

  -- Gassy mine conditions are assumed; thus, a seven panel-entry design with five main entries is employed, with permissible mining equipment for use in gassy environments. Studies have indicated that planning for gassy mine conditions appreciably increases capital and operating costs for mining operations. However, this additional cost is negligible when compared to the total plant facility costs. Further, post-operating design changes or retrofitting a mine to gassy conditions when such conditions are not anticipated initially, is a major project cost.

Exhibit 2-1

PROCESS FLOW DIAGRAM: CASE 3



* ALSAR = Alumina Soda Ash Recovery

-- Access to the mine is through parallel inclines of about 12,000 feet in combined length. A detailed analysis of shaft versus incline access was performed and the incline chosen because it was technically and economically superior for the large tonnage output of the mines.

-- Hydraulic backfilling is assumed. This may create a disposal problem since the finest particles must be removed on the surface so that the fill can stabilize. This could be accomplished through large surface settling ponds which may have adverse environmental impact. An alternative is to use pneumatic backfilling, but with the large tonnages involved the feasibility of such an operation appears highly questionable.

After mining the shale is crushed on the surface and the nahcolite is separated. The design of the nahcolite separation unit is based on a previously published design, adapted to this situation. Two products will be produced for stack gas or baghouse scrubbing; the first is -1/8" material and the second is +1/8" material.

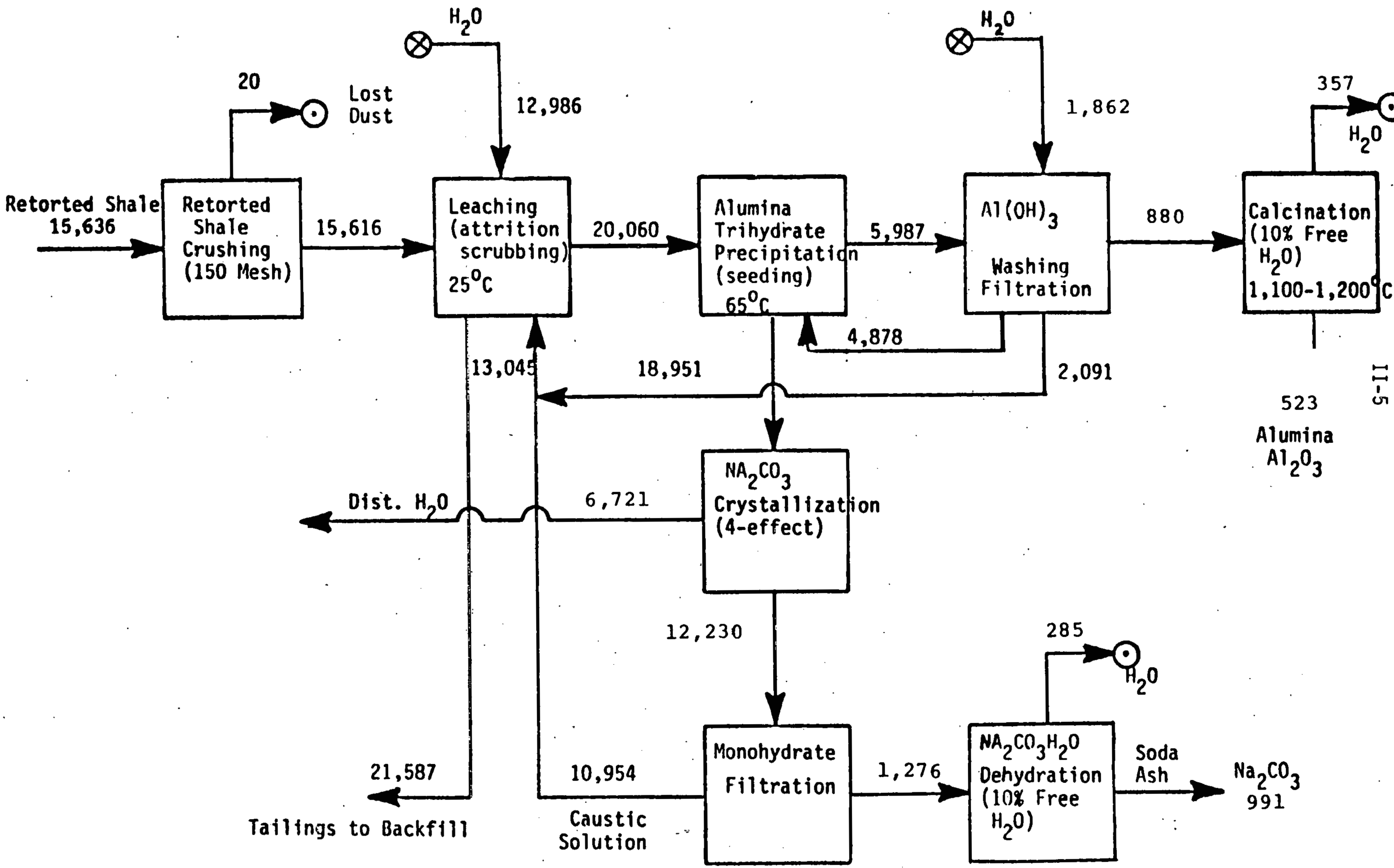
The retort design is based on published data for commercial-scale circular grate retorts. This retort can process 20,000 tons per day and produces shale oil, offgas and spent shale.

After retorting, the dawsonite in the spent shale is upgraded to alumina and soda ash in the Alumina Soda Ash Recovery (ALSAR) unit. The process design of these facilities is shown conceptually on Exhibit 2-2 and is discussed below. Also shown on Exhibit 2-2 are the mass flows for Case 3.

- The retorted shale is crushed to 150 mesh to provide sufficient contact surface area for leaching.
- The next step is "cold" leaching (25°C) of retorted shale with caustic concentrations of NaOH less than or equal to 20 g/l, and Na_2CO_3 less than or equal to 150 g/l for control of silica dissolution.
- Then, solubilized alumina is recovered from leach liquor by "hot" precipitation (65°C) using recycled trihydrate seeding (5:1 ratio).

Exhibit 2-2

ALUMINUM AND SODA ASH RECOVERY FACILITIES: CASE 3



- Cell-grade alumina is produced (less than or equal to 0.03% weight of SiO_2) from the precipitated $Al(OH)_3$ after washing, filtration, and calcination.
- The process is self-sufficient in caustic (NaOH), and the pH of the overflow from precipitation is controlled by Na_2CO_3 crystallization and a caustic purge in the retorted shale leaching recycle step. Caustic concentrations are carefully regulated for control of silica solubility.
- Finally, soda ash (dense) is produced by evaporation of the overflow leach liquor and dehydration of the monohydrate product.

The retorted shale must be finely crushed prior to leaching, since solubilization of the aluminum values is strongly dependent on surface-area contact.

A potential cost-savings of the assumed production process relative to other proposed designs is the obviation of a de-silication circuit in the ALSAR unit. Also, no line-sinter processing is required for silica control and leach water clean-up.

Energy Balance

In addition to mass balance calculations, energy balances for the shale oil and mineral co-product facilities were determined. The purpose of this part of the study was to evaluate the potential of using the low BTU offgas from the retort as a co-product for alumina calcination and soda ash crystallization. In the ALSAR process, a substantial quantity of process heat in the form of high and low-pressure steam is required. Based on analogies with the aluminum and trona industries, these processes require:

Process Step	Energy Requirements
Alumina Precipitation	6.7 MMBtu/ton
Soda Ash Crystallization	7.2 MMBtu/ton

The data available for circular grate-type retorts indicate that 14.5 x 10^9 BTU per day of 90 BTU per cubic foot of gas is produced by a single 20,000 BPD retort module.

The plant in Case 3 is estimated to consume 13.8 x 10^9 BTU/day as follows:

ALSAR Facility	Energy Consumption 10^9BTU/day
Nahcolite Recovery Unit (Photosort Kiln)	1.3
Na_2CO_3 Crystallizer	6.2
$Al(OH_3)$ Kiln (Fluidized-Bed Calciner)	3.2
Na_2CO_3 Kiln	0.7
Process Drives	1.0
Misc. Plant	1.4
Total	13.8

This indicates that the retort offgas will be sufficient to meet the process energy requirements of the upgrading facilities. In addition, the plant will require the use of diesel in the mining operations and electricity which must be purchased. The energy requirements for the five cases are shown on Exhibit 2-3.

Costing

The major plant sections of the shale oil and mineral co-products facility are listed in Exhibit 2-4. For each of the five cases analyzed, the individual plant sections listed in Exhibit 2-4 were characterized by: (1) process-flow, mass and energy balances (as discussed above), and; (2) equipment capacity and performance, labor, and material quantity calculations.

Exhibit 2-3

Energy Requirements for the Shale Oil and Co-Product Facilities

Energy Requirements	Case 1	Case 2	Case 3	Case 4	Case 5
Shale Oil					
- diesel, MMGPY	1.1	4.5	1.3	4.2	6.9
- electricity, MW	20.2	73.1	24.3	69.0	113.0
Alumina					
- offgas, 10^9 BTU/day	0.5	2.0	3.2	9.6	16.0
- electricity, MW	12.2	50.1	16.4	47.0	78.1
Soda Ash					
- offgas, 10^9 BTU/day	2.6	3.2	6.9	20.8	34.7
- electricity, MW	0.8	1.8	2.5	7.5	17.0

Exhibit 2-4

Major Plant Sections of a Commercial Shale Oil/Mineral Co-Products Facility

Plant Section	Function/Output
Mining	
Mine (Room and Pillar)	ROM Shale
Primary Crushing	-8" Shale
Conveying	
Nahcolite Recovery Unit	
Shale Stockpile	Storage
Secondary Crushing	-3" Shale
Nahcolite Recovery (Screening and Photosorting)	Nahcolite Products (Baghouse/Stack Scrubber Material)
Retort and Oil Recovery	
Retort and Oil Recovery	Raw Shale Oil
Gas Recovery	Low BTU Gas
Syncrude Handling and Distribution	Storage - Loading
ALSAR[1/] Plant Section	
Retorted Shale Crushing	-150 Mesh
Crushed Shale Leaching	Soluable Extraction
Aluminum Trihydrate Precipitation	$Al(OH)_3$
Alumina Calcination	Alumina (Al_2O_3)
Soda Ash Crystallization	$Na_2CO_3 \cdot H_2O$
Soda Ash Dehydration	Na_2CO_3 (Dense)
Product Handling & Distribution	Storage - Loading
Process H_2O Treatment	
Water Treatment	Process Water Cleanup
Wells/Mine Dewatering	Water Supply
Underground Hydraulic Shale Disposal	
Slurry Pumping Unit	Slurry Transportation
Settling Pond/Recirculation	Stabilization/Recovery
General Plant Facilities	
Utilities	General Support and Services
Administration Buildings	
Warehouses, etc.	

1/ Alumina and Soda Ash Recovery

Exhibit 2-5 summarizes the capital and operating cost components for all facilities in Case 3.

Based on the material balances and equipment capacity calculations, the equipment for each plant section was determined. These equipment inventories enabled cost estimates to be prepared from detailed capacity-cost relationships available in the literature. These data sources are derived from historical plant operations extending over many thousands of plant facilities. Further, a large number of vendor quotes were secured for the major pieces of equipment and checked against independent data sources for accuracy.

Case 3 was selected as the fundamental engineering design case from which the plant costs and power requirements of the remaining four cases were scaled. In this step, the major plant sections in Exhibit 2-4 were further factored into an inventory of major equipment components. The equipment size, capacity, and performance ratios were calculated, and using the capacity-cost relationships discussed above, the installed-plant equipment capital and material operating costs were determined. Total operating costs for the plant sections were determined by the power and process fuel requirements and the development of operating and maintenance labor schedules.

All capital and operating cost data were normalized to a FY 1980 level using the Marshall and Stevens Chemical Plant Equipment Index. This index enables historical cost data to be updated to current costs, and was extensively cross-checked using vendor quotes for major equipment purchases.

Labor costs (wages) were calculated from data published by the U.S. Bureau of Labor Statistics and reflect the anticipated growth of these costs under a realistic scenario of shale oil development in the Western United States.

Exhibit 2-5

CASE 3 Unburdened Costs

(Dollars in Millions)

Facility	Capital Cost	Operating Costs: Material	Labor	Power (MW)	Process Gas (10^9 BTU/day)	Diesel (10^9 gal/yr)
Mining/Primary Crushing	29.9	0.2	16.7	8.2	--	1.3
Nahcolite Recovery Unit	33.3	1.2	2.6	2.4	1.3	--
Retort/Oil and Gas Handling	112.7	11.9	3.8	7.4	0.2 1/	--
Process and Plant H_2O Facilities	4.0	0.3	1.7	1.4	--	--
Slurry Disposal	1.9	1.1	2.8	3.6	--	--
General Plant Facilities	10.3	1.3	1.7	1.3	0.7	--
Total	192.1	16.0	29.3	24.3	2.2	1.3
ALSAR Plant						
Retorted Shale Crushing & Leaching	26.3	2.0	4.5	13.5	--	--
$Al(OH)_3$ Precipitation and Washing	4.5	0.2	0.8	1.2	--	--
$Al(OH)_3$ Calcination	16.1	1.0	2.4	1.7	3.2	--
Na_2CO_3 Crystallization and Filtration	12.3	1.1	1.9	1.7	6.2	--
Na_2CO_3 Dehydration	3.9	0.7	0.7	0.8	0.7	--
Total	63.1	5.0	10.3	18.9	10.1	0

1/ Does not include recycle gas to retort.

Extrapolation of the calculated Case 3 costing data to the remaining cases is achieved by an exponential scaling method. This procedure accounts for major economies of scale and non-linear effects in the cost scaling analysis. A weighted average scaling exponent is derived for each plant section by obtaining a standard scaling exponent from the literature for the principal pieces of equipment in each section, and weight-averaging these exponents against the total section capital cost. Thus, an overall scaling exponent for each plant section listed on Exhibit 2-5 was derived and used in the capital cost analysis for the remaining four cases.

The material operating cost component was similarly extrapolated from the Case 3 data using a separately derived sequence of engineering scaling exponents. Operating and maintenance labor schedules were defined for the remaining cases and the operating cost components for each plant section determined, as shown on Exhibit 2-5.

Summary of Manufacturing Costs

The table below summarizes the unburdened costs that would be incurred for the shale oil plant, the alumina and the soda ash facilities.

	Capital Costs, $MM	Operating Costs	
		Material & Labor, $MM	Elec., MW
Shale Oil	192.2	45.3	24.3 1/
Alumina	46.9	10.8	16.4
Soda Ash	16.2	4.4	2.5

1/ In addition, 1.3 x 10^6 gal/year of diesel fuel is used in the mining operations.

Seventy-five percent of the total capital outlay is due to the shale oil plant, mainly the Nahcolite Recovery Unit and the Retort. Seventy-five percent of the operating costs and 55% of the electric power costs are also attributable to the oil plant. The alumina plant costs about 20% of total capital and the two major capital items are the Retorted Shale Crushing and Leaching and Alumina Calcination. Similarly, operating costs are about 20% and electric power requirements are about 40% of the total. Finally, soda ash facilities only cost about 5% of the total capital investment and their operating costs and electric power requirements are about 5% of the total as well.

CHAPTER III

ECONOMIC ANALYSIS

Summary

This chapter describes and summarizes the major findings of the economic analysis for shale co-products.

The results show that in Case 3, which is a 15,639 barrel per day demonstration plant at a rich minerals site, the cost of raw shale oil is $26 per barrel, the cost of alumina is $257 per ton, and the cost of soda ash is $77 per ton at a 15% rate of return. This compares with estimated current market values of $25 per barrel for raw shale oil (before hydrotreating), and $220 to $260 and $90 per ton domestically for alumina and soda ash, respectively. Overall, with the recovery of the co-product minerals, the integrated unit is marginally economic at current world oil prices. As the size of the plant is increased to full commercial scale, the shale oil plant becomes economic on its own and the production of the mineral co-products further improve these economics. These market values are approximate because the shale oil would need to be upgraded, a free market value for alumina does not currently exist, and both the alumina and soda ash could incur large transportation costs in delivery to markets. Importantly, included in these economic results is an escalation of 2% per year in energy costs for the alumina and soda ash. Thus, the derived costs for alumina and soda ash would not escalate while the prices of competing products would, making co-product alumina and soda ash increasingly more economic.

Introduction

The basis for the economic analysis is the process flow diagrams and operating and capital costs developed by Energy Development Consultants (EDC).

The economic analysis assumes that the costs of the plant units are allocated to either the production of oil, alumina, or soda ash. The rationale used in this allocation is to assume that the plant initially is constructed for the production of shale oil. Then, additional facilities are added for the alumina production. Finally, the facilities needed to produce soda ash are added. This rationale leads to plant units being allocated in the following manner:

Shale Oil Plant	Alumina Plant	Soda Ash Plant
Mine	Shale Crushing	Crystallization
Primary Crushing	Leaching	Dehydration
Nahcolite Recovery Unit	Precipitation	
Retort	Calcination	
Water Processing	Product Handling	
Slurry Disposal		
General Plant Facilities		

The nahcolite recovery unit is attributed to the shale oil plant since the nahcolite must be separated out prior to retorting to avoid fusing of the charge.

This allocation of capital and operating costs has been chosen even though some units are necessary for the production of both co-products, for example leaching and shale crushing is essential to alumina and soda ash production. However, if it is assumed that the alumina is a primary co-product, then the units are necessary for alumina production, and the chosen allocation would be the correct one.

Estimates of Capital and Operating Costs

The capital and operating costs developed by EDC are the base costs to purchase components, construct the individual facilities for each unit and operate them. A summary of these costs is provided on Exhibit 2-5. Beyond these base purchase costs are the expenses incurred in interconnecting the units and the overhead of operating and maintaining the plant. To reflect the "as installed" costs, the following capital and operating burdens were used, based on published data:

Capital Burdens. A total capital burden of 27.1% of the cost developed by EDC was assumed.

Operating Burdens. Two operating burdens were assumed; 20% of the base capital costs for maintenance; and 50% of labor costs for indirect costs. For the mine, only the latter burden is applicable, and it is equal to 20¢ per ton mined for the indirect costs on labor.

The burdened operating, labor and material costs, shown on Exhibit 3-1, were developed from the details for the individual plant units that EDC provided for Case 3. These costs were scaled to the four other cases using operating scale factors developed by EDC.

Economic Assumptions

The following major economic assumptions were used in the analysis:

Royalties and Severance Taxes. Royalties of 12.5¢ per ton mined and severance taxes of 4% of the selling price were assumed for the oil. No severance tax was assumed for the co-products.

Exhibit 3-1

CASE 3 Burdened Costs
(Dollars in Millions)

Facility	Capital Cost	Operating Costs: Material	Labor	Power (MW)	Process Gas (10^9 BTU/day)	Diesel (10^9 gal/yr)
Mining/Primary Crushing	38.0	0.2	21.6	8.2	--	1.3
Nahcolite Recovery Unit	42.3	2.9	4.0	2.4	1.3	--
Retort/Oil and Gas Handling	143.3	17.6	6.1	7.4	0.2 1/	--
Process and Plant H_2O Facilities	5.0	0.5	2.8	1.4	--	--
Slurry Disposal	2.1	1.1	4.9	3.6	--	--
General Plant Facilities	13.1	1.7	2.9	1.3	0.7	--
Total	243.8	24.0	42.3	24.3	2.2	1.3
ALSAR Plant						
Retorted Shale Crushing & Leaching	33.4	3.3	6.7	13.5	--	--
$Al(OH)_3$ Precipitation and Washing	5.7	0.4	1.2	1.2	--	--
$Al(OH)_3$ Calcination	20.4	1.9	3.5	1.7	3.2	--
Na_2CO_3 Crystallization and Filtration	15.6	1.6	3.0	1.7	6.2	--
Na_2CO_3 Dehydration	4.9	0.9	1.1	0.8	0.7	--
Total	80.0	8.1	15.5	18.9	10.1	0

1/ Does not include recycle gas to retort.

Escalation Factors. All costs were taken as first quarter, 1980 costs, except for energy costs. These were assumed to escalate 2% a year in real terms.

G&A. G&A was assumed to be 15% of the operating costs not dependent upon energy, i.e., labor and materials. During the first years when the plant was being constructed, G&A was assumed to be 10% of the annual investment.

Construction Schedule. The construction schedule for the shale oil plant was assumed to be six years and the investment was assumed to be incurred uniformly, except for the first and last years.The soda ash and alumina plants were assumed to be essentially constructed in half the time of the shale oil plant, but to be completed at the same time.

Depletion. A depletion allowance of 15% for the shale oil and 14% for the minerals was assumed.

Front-End Costs. Based on data for planned projects, front-end costs of $115 million were assumed for plant design and pre-development. This same amount was assumed for each case, independent of plant size.

Investment Tax Credits. Investment tax credits of 10% were assumed in the year of capital expenditure.

Taxes. A Federal tax rate of 46% and a state tax rate of 3% were assumed. Tax credits were assumed to be used in the year incurred. This assumes that the company building a shale oil plant has other income to which the tax credits can be applied.

Working Capital. Working capital during the construction period is assumed to be 10% of the current and subsequent year's investment. During the operating life of the plant, working capital was assumed to be sixty days of the operating costs plus G&A.

Energy Costs. Energy costs of $1 per gallon for diesel fuel (1980 prices) were assumed. Electric power was assumed to cost 5¢ per kilowatt-hour, and offgas was assumed to have a value of $5 per million Btu.

Economic Results

The results of the economic analyses for shale oil, alumina, and soda ash are shown in Exhibit 3-2 for a 15% discount rate.

Two major assumptions distinguish this study from the recently published Office of Technology Assessment report. The shale oil is assumed to be raw, without hydrotreating or other upgrading. Assuming a current crude oil cost of $35 per barrel and a discount of about $10 per barrel for upgrading, shale oil in this study must cost less than $25 per barrel to be competitive. In addition, energy costs, and therefore the price of shale oil, were assumed to increase 2% per year in real terms. This has a major effect on economics, as will be discussed.

Upgrading the soda ash and alumina will require large amounts of energy in the form of heat which would have to be purchased. However, the retort produces sufficient volumes of low BTU gas to meet these requirements and it was therefore assumed that it would be purchased at the cost of alternate energy, assumed to be the current decontrolled price of energy, or $5 per million BTU. The sale of offgas improves the economics of shale oil production by $0.40 to

Exhibit 3-2

Shale Co-Product Study

Economic Results

($/Bbl. or $/Ton)

Case	Rich Shale, Lean Minerals 1	2	Rich Shale, Rich Minerals 3	4	Lean Shale, Rich Minerals 5
Shale Oil (with $5 per MMBTU Credit)					
Escalating Price +2% per year	26.1	19.8	26.3	19.5	26.3
Escalating Price w/o offgas credits	27.1	20.2	29.2	22.4	30.7
Constant Price	33.5	25.4	33.6	25.0	33.4
Alumina					
with offgas costs	1028	887	257	229	205
w/o offgas costs	990	849	222	194	170
Soda Ash					
with offgas costs	339	116	77	74	71
w/o offgas costs	151	58	37	34	31

$1.00 per barrel in cases 1 and 2 (the "low minerals" cases) and $2.90 to $4.40 per barrel in cases 3, 4 and 5 (the "high minerals" cases).

Thus, the "sale" of low BTU gas to the co-product facilities can improve the economics of shale oil significantly.

Rich Shale, Lean Minerals Cases

Cases 1 and 2 are the rich shale, lean minerals cases. The shale oil economics look marginally attractive for Case 1 and quite attractive for Case 2, the 50,000 barrel per day plant. One reason for this is that no nahcolite recovery unit is required, which is a major cost item in the other cases. However, the main purpose of this study was to determine the mineral co-product economics and these are unattractive. Although no market price for alumina currently exists, a 1980 market price of about $230 to $270 per ton has been estimated, FOB. However, the cost of co-product alumina is more than $800 per ton. Soda ash is a by-product of alumina manufacturing and would not be produced unless alumina recovery itself were economic. The recovery of co-product minerals in deposits with lean minerals content exemplified by Cases 1 and 2, are thus uneconomic.

Rich Shale, Rich Minerals Cases

Cases 3 and 4 are the rich shale, rich minerals cases and they constitute the Base Cases.

Assuming a 2% per year escalation in energy costs and the sale of offgas, case 3, the single unit plant, appears marginally economic at $26.30 per barrel of shale oil, while case 4, the full size commercial plant, appears to have favorable economics at $19.50 per barrel. Without the 2% per year escalation in real prices, the required market threshold price increases to $33.60 and $25.00 per barrel in cases 3 and 4, respectively.

The co-product alumina and soda ash recovery costs are competive at current market prices or prices estimated for 1990 and later years, as shown below:

	1990 Estimated Market Price, $/Ton (1980 $)		
	Co-Products		Competitive Processes
	Case 3	Case 4	
Alumina	257	229	230-270
Soda Ash	77	74	82-142[1]

[1] The estimated international price after deducting $68 per ton to equalize transportation costs.

Exhibits 3-3 and 3-4 show the economics for the alumina and soda ash plant in Case 3. These Exhibits show the major costs that would be incurred and equations for the after-tax annual revenue. By separating the cost and revenue cash flow in this manner and discounting them separately, the alumina and soda ash prices can be found directly without iteration.

A comparison between the co-product costs for cases 3 and 4 in the table above shows the potential for economies of scale. Alumina prices decrease $29 per ton while soda ash prices only decrease $3 per ton. The reason for this is detailed on the following table; direct operating costs and offgas costs are proportional to the tonnage produced, while economies of scale would be reflected in capital charges, other costs and taxes. These "other" costs constitute $91 per ton of alumina, but only $15 per ton for soda ash, as summarized below:

	Dollars per Ton	
	Aluminum	Soda Ash
Direct Operating Cost	131	22
Offgas (Energy) Costs	35	40
Other	91	15
Total	257	77

EXHIBIT 3-3

CASE 3

Alumina Plant Economics
(Millions of Dollars)

Year	1	2	3	4	5	6	7	8	9	10	15	20	25	28
Annual Production, 10^6 tons	--	--	--	--	--	--	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Operating Cost	--	--	--	--	--	--	5.0	11.7	16.7	16.7	16.7	16.7	16.7	16.7
Power (16.4 MW)	--	--	--	--	--	--	2.4	5.8	8.4	8.6	9.5	10.4	11.5	12.2
G&A	0.3	0.3	0.3	1.8	1.8	1.5	0.8	1.8	2.5	2.5	2.5	2.5	2.5	2.5
Depreciation	0.3	0.6	0.8	2.5	4.1	5.1	5.0	4.2	3.4	3.0	1.8	1.1	1.0	1.0
Net Cost Before Tax Effects	(0.6)	(0.9)	(1.1)	(4.3)	(5.9)	(6.6)	(13.2)	(23.5)	(31.0)	(30.8)	(30.5)	(30.7)	(31.7)	(32.4)
Federal Tax	0.3	0.4	0.5	2.0	2.7	3.0	6.1	10.8	14.3	14.2	14.1	14.1	14.6	14.9
State Tax	--	--	--	0.1	0.1	0.1	0.2	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Net Cost After Tax Effects	(0.3)	(0.5)	(0.6)	(2.2)	(3.1)	(3.5)	(6.9)	(12.3)	(16.2)	(16.1)	(15.9)	(16.1)	(16.6)	(17.2)
Investment	(3.0)	(3.0)	(3.0)	(17.9)	(17.9)	(14.7)	--	--	--	--	--	--	--	--
ITC	0.3	0.3	0.3	1.8	1.8	1.5	--	--	--	--	--	--	--	--
Depreciation	0.3	0.6	0.8	2.5	4.1	5.1	5.0	4.2	3.4	3.0	1.3	1.1	1.1	1.1
Working Capital	(0.6)	--	(1.5)	(1.5)	(0.3)	(1.8)	(0.5)	(1.2)	(1.0)	--	--	--	--	3.2
Cash Requirements	(3.3)	(2.6)	(4.0)	(17.3)	(14.8)	(9.8)	(1.4)	(9.3)	(13.8)	(13.1)	(14.1)	(14.9)	(15.6)	(12.8)

Annual Revenue = [Production · Alumina Price - Depletion-Offgas Cost] (1 - Federal Tax) (1-State Tax) + Depletion
= Production · Alumina Price · 0.590 - Offgas Cost · 0.524

The alumina facilities use $3.2 \cdot 10^9$ BTU/day of offgas.

EXHIBIT 3-4

CASE 3

Soda Ash Plant Economics
(Millions of Dollars)

Year	1	2	3	4	5	6	7	8	9	10	15	20	25	28
Annual Production, 10^6 tons	--	--	--	--	--	--	0.1	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Operating Cost	--	--	--	--	--	--	2.0	4.6	6.6	6.6	6.6	6.6	6.6	6.6
Power (2.5 MW)	--	--	--	--	--	--	0.4	0.9	1.3	1.3	1.4	1.6	1.8	1.9
G & A	0.1	0.1	0.1	0.6	0.6	0.5	0.3	0.7	1.0	1.0	1.0	1.0	1.0	1.0
Depreciation	0.1	0.2	0.3	0.9	1.4	1.8	1.6	1.5	1.3	1.2	0.7	0.4	0.4	0.4
Net Cost Before Tax Effects	(0.2)	(0.3)	(0.4)	(1.5)	(2.0)	(2.3)	(4.3)	(7.7)	(10.2)	(10.1)	(9.7)	(9.6)	(9.8)	(9.9)
Federal Tax	0.1	0.1	0.2	0.7	0.9	1.1	2.0	3.5	4.7	4.7	4.5	4.4	4.5	4.6
State Tax	--	--	--	--	--	--	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Net Cost After Tax Effects	(0.1)	(0.2)	(0.2)	(0.8)	(1.1)	(1.2)	(2.2)	(4.1)	(5.3)	(5.2)	(5.0)	(5.0)	(5.1)	(5.1)
Investment	(1.0)	(1.0)	(1.0)	(6.2)	(6.2)	(5.1)	--	--	--	--	--	--	--	--
ITC	0.1	0.1	0.1	0.6	0.6	0.5	--	--	--	--	--	--	--	--
Depreciation	0.1	0.2	0.3	0.9	1.4	1.8	1.6	1.5	1.3	1.2	0.7	0.4	0.4	0.4
Working Capital	(0.2)	--	(0.5)	(0.5)	0.1	0.6	0.1	(0.3)	(0.1)	--	--	--	--	0.8
Cash Requirements	(1.1)	(0.9)	(1.3)	(6.0)	(5.2)	(3.4)	(0.5)	(2.9)	(4.1)	(4.0)	(4.3)	(4.6)	(4.7)	(3.9)

Annual Revenue = [Production · Soda Ash Price - Depletion - Offgas Credit] (1 - Federal Tax) (1 - State Tax) + Depletion
= Production · Soda Ash Price · 0.590 - Offgas Cost · 0.524

The soda ash facilities use 6.9 · 10^9 BTU/day of offgas.

The preceeding table also shows the large costs for energy: $35 per ton for alumina and $40 per ton for soda ash. Because the low BTU offgas from the shale oil plant may not have a market otherwise, mineral co-products can contribute to the economies of the shale oil plant if the minerals can be sold at costs that include a value for the offgas. Varying the transfer price of offgas can provide considerable flexibility in the pricing of the co-products or can be used to improve the economics of the shale oil -- assuming that no alternative use of the offgas would be available, as for example, on-site generation of electricity.

Lean Shale, Rich Minerals Case

Case 5 analyzes a full scale commercial size facility for an area with lean shale and rich minerals content. The shale oil economics in this case are substantially inferior to case 4, but comparable to case 3. With the sale of the offgas, a threshold price of $26.30 is required. This price is a little higher than the assumed threshold market price for raw shale oil.

Because of the large volumes of raw shale mined, the mineral co-product economics reflect economies of scale and are the most favorable of the five cases. The manufacturing cost of alumina drops to $205 per ton and the cost of soda ash to $71 per ton, well below current market prices. The major finding is, therefore, that the integrated plant producing shale oil, alumina, and soda ash is economic and that the co-products can make lower grade oil shale in the Northern Piceance Basin economic, which would otherwise be uneconomic.

CHAPTER IV

THE MARKET POTENTIAL FOR SHALE CO-PRODUCTS

Summary

Basic restraints of plans for widespread recovery of co-product minerals from shale oil have been the concerns that the processing costs will be too high and that the resulting production of soda ash and alumina would overwhelm existing markets. A further complication has been the calculation of economic feasibility in a multi-product, joint cost setting. This study however finds that the economics of shale co-production, particularly when major parts of the manufacturing process can be jointly utilized, provide major opportunities to share and shift costs among the end-products, as market prices allow.

The four end-products -- shale oil, alumina, soda ash and nahcolite -- produced by the shale oil co-product plant share many of the same facilities, particularly in mining the ore. In addition, they can take major advantage of otherwise waste energy, such as the excess process heat and low BTU offgas produced. Thus the amount of joint production facilities is substantial. Should the basic shale oil facility be economic producing the primary product, the mineral co-products would need only to bear much smaller incremental costs to be price competitive.

The underlying condition for economically feasible recovery of alumina, soda ash, and nahcolite from spent oil shale is that the marginal costs of production will be significantly less than the competitive market values for these products. A commercial facility

for recovery of soda ash and alumina from retorted shale thus requires the following conditions:

- The product quality will be compatible with the prospective end uses and the supply will be reliable.
- The products can be manufactured and delivered to markets at competitive prices.
- There will be adequate markets to absorb the production without significant effect on the product price.

A market study of minerals is especially dependent upon the assumptions used in the analysis. Market constraints and preferences are inherently subjective and a function of the analyst's definition of what constitutes the market. In the case of shale co-products, the two most important assumptions used are that the markets are international and that the products with the most favorable economics will ultimately penetrate the market. The full set of assumptions used in the study are shown on Exhibit 4-1.

The demand for alumina, soda ash and nahcolite differs substantially. Alumina has essentially only one end use as a raw material for primary aluminum manufacturing by electrolytic reduction. Soda ash, while heavily dependent upon glass as a major market, has a wide range of other applications and can be a direct substitute for caustic soda (sodium hydroxide) in many end uses, or can be indirectly substituted by simple causticization with calcium hydroxide. Future nahcolite markets are directly related to air control technology choices yet to be made by utilities.

The major competitors of oil shale based alumina are the processors of imported bauxite (principally from Jamaica) and imports of alumina (principally from Australia). Current tax levies imposed by these exporting countries greatly influence the costs of the competing products. Oil shale based soda ash is faced with an

Exhibit 4-1

Key Assumptions Used in Analysis of Co-Product Market Potential

Nine key assumptions formed the base for the analysis of the market potential for the shale co-products of alumina, soda ash and nahcolite:

1. The outlook for primary markets for oil shale based co-products will be largely determined by the function and cost effectiveness of the secondary products in end use applications.
2. Commodity selling prices will largely track the manufacturing economics of the dominant process.
3. Alumina and soda ash are international trade products and no serious trade barriers will be artificially constructed.
4. Environmental constraints in the future will not differ significantly from those of 1980.
5. Energy costs will rise at 2% per year, in 1980 constant dollars.
6. Existing involuntary supplies of products will move preferentially to market.
7. Captive markets will be preferentially served by captive producing facilities.
8. Inter-product substitution will only take place where price differentials, on an equivalent basis, are seen by buyers to be fundamental, rather than transient.
9. Oil shale based products will be substitutional in quality and performance with currently available commercial materials.

analogous competitive product, caustic soda, whose supply is a dependent variable of the demand for chlorine. Since chlorine markets are quite dissimilar from those of caustic soda and are growing at a lower rate, sizeable imbalances in the demand and supply of chlorine based caustic could occur in the future. Because chlorine demand has not increased substantially recently and could decrease in the future, shortfalls in the supply of chlorine based caustic could result in a rising demand for soda ash based sources. The major competitor to nahcolite is not another chemical product, but rather competing air control technologies that will be available to coal burning utilities.

Because the raw material source is land locked and in a new supply area, transportation costs to markets play an influential role in the economics of oil shale minerals recovery. For alumina, the transportation costs could provide some market advantage to the large, low-energy cost aluminum smelters of the Northwest. For soda ash, transportation would add about 75% to production costs for overseas markets. Transportation would be the major cost item for nahcolite.

Finally, the market potential for the oil shale mineral derivatives -- alumina, soda ash and nahcolite -- is very much dependent upon governments.

- The U.S. Government needs to determine the national security value of having a substantial domestic source of alumina and aluminum, vital defense and transportation commodities. In addition, if the U.S. is to have any influence over future tax and pricing decisions of the International Bauxite Association (IBA), a cartel of bauxite producing nations, and thus maintain a competitive domestic aluminum industry, it will need a substantial domestic source of alumina.

- Foreign governments, particularly those of Western Europe, will need to provide access to U.S. exports of soda ash and chlorinated products. In addition, they will need to reexamine their bilateral trade policies with COMECON countries that may lock them into future high cost sources of soda ash.

Assuming the actions taken by domestic and foreign governments are favorable, the market economics of oil shale based alumina and soda ash appear attractive. However, the market for nahcolite is less certain, and is limited by freight costs and dependent on the selection by utilities of control technologies where dry scrubbing agents are preferable.

1. Markets for Alumina (Al_2O_3)

Co-product alumina is a high potential product because of its inherent domestic advantages -- security of supply, freedom from offshore tax policies of supplier nations, and possibly lower transportation costs.

One of the most significant advantages a domestic alumina source would have is that the cost would be decoupled from foreign tax formulae. Since these are exponential in their cost effects, being tied to increases in the finished aluminum price rather than bauxite mining costs, use of foreign alumina guarantees a "piggyback" increase on raw material costs even though real costs may not rise at that rate. The development of alumina from oil shale dawsonite is virtually the only way the U.S. can hold primary aluminum costs within competitive bounds, and affords a real advantage in world markets where other producers must use IBA material.

Because of security of supply and competitive production costs, it is likely that the bulk of growth in the domestic alumina market can be met from domestic based co-product alumina. In addition, because the existing domestic plants are 20 to 60 years old, this source of alumina can readily replace from 20% to 40% of current domestic capacity, as existing plants are retired. Less certain future markets are the replacement of current alumina imports from

Australia and the development of markets tied to new Western Canadian aluminum smelting capacity. The competitive future market price of alumina has been determined from current costs (and taxes) required to produce alumina from imported bauxite, escalated for real increases in energy costs.

Based on these assumptions, the market outlook for domestically produced alumina from dawsonite is projected at 6 to 11 million tons per year by the year 2000, equivalent to the output of a 450,000 to 850,000 barrels per day shale oil enterprise. The price of alumina is expected to escalate by the year 2000 to a range of $240 to $280 per ton (in 1980 dollars), compared to the $257 per ton cost of co-product alumina. Further detail on the potential market demand and price is provided below:

	Potential Market Demand		Potential Market Price
Year	Million Tons/Year	Equivalent MB/D Shale Oil Capacity	($/Ton; 1980 $)
1990	3-5	230-400	$230-$270
2000	6-11	450-850	$240-$280
2010	9-16	700-1,250	$250-$290

2. Markets for Soda Ash (Na_2CO_3)

The potential of co-product soda ash will be a function of access to the West European and Asian markets. The West European market availability, in turn, is a function of future Solvay process costs, protectionist efforts by producing nations, and East European marketing policies and production capability. A second element in the outlook for soda ash demand is what the relative balances between caustic soda supply and demand will be, which will largely depend on chlorine demand for VCM.

On balance, the future market outlook for natural and co-product soda ash appears better than the overall market for sodium oxide. This favorable interpretation is based upon the following assumptions:

- Solvay process costs will become too high to compete with naturally produced soda ash;
- U.S. production will have access to the European and Japanese markets; and,
- Chlorine demand will remain stable, requiring soda ash to meet the bulk of future demand growth for sodium oxide.

The major questions which cannot be answered at this time are how reliable a supplier COMECON producers will be to Western Europe, and how protective Western Europe will be of domestic producers of soda ash and chlorinated products. If COMECON countries are unable to meet demand at competitive prices, there may be significant opportunities for new soda ash exports to Europe (especially low cost exports), if there are no major blocks to entry.

The lower estimates of future market demand assume that natural soda ash will be able to displace European and ultimately Japanese Solvay Process based soda ash production. In addition, the demand estimates assume that oil shale based soda ash will share, essentially equally with trona mining, the domestic demand growth for sodium oxide minerals. A more speculative future soda ash market involves the substitution of soda ash for caustic soda, assuming the world demand for chlorine and chlorinated products remains level or declines. The estimates of future prices are based on the marginal raw material, fuel and operating costs of the Solvay process, escalated by real increases in the cost of energy.

Based on these assumptions, the market outlook for soda ash produced as a by-product from dawsonite is projected at 9 to 12 million tons per year by the year 2000, equivalent to the output of a 400,000 to 500,000 barrels per day shale oil enterprise. The market price is expected to escalate by the year 2000 to a range of $60 to $100 per ton domestically (governed by trona mining costs) and $170 to $230 per ton in Western Europe or Japan (in 1980 dollars). Further detail is provided below:

	Potential Demand		Potential Price ($/Ton; 1980 $)	
	Million Tons/Year	Equivalent MB/D Shale Oil Capacity	Domestic	International
1990	4-5	170 - 220	50 - 95	150 - 210
2000	9-12	400 - 500	60 - 100	170 - 230
2010	14-18	600 - 800	70 - 110	200 - 260

3. Markets for Nahcolite(Na_2HCO_3)

The future markets for nahcolite will be affected primarily by the choice of scrubbing technology to be made in this decade by the utility industry. In addition, freight costs are critical to the economic viability of nahcolite. Since nahcolite is only 28% Na_2O, it is necessary to haul about two times the weight of material per ton of Na_2O as with soda ash.

If the spent nahcolite could be resold to pulp mills, there would be credits available against raw chemical costs. These markets are largely in the South and Southeast U.S., so freight charges would likely be high. However, the trend is toward reduction of chemical demands, together with using soda ash or caustic for Na_2O makeup.

It would appear the market for nahcolite can be as much as one million tons per year by 1990 (equivalent to the output of a 15,000 barrels per day unit in a nahcolite rich area). Moreover, the market will need to be in areas close to the source so that freight charges are minimal and targeted to utilities having control technologies where dry scrubbing is applicable. The projected future market price will be based largely on the freight costs plus the incremental costs of converting the mined material to meet utility specifications.

The Market Potential for Alumina

1. Introduction

Alumina, or aluminum oxide (Al_2O_3), is the primary raw material that reduces to aluminum, a lightweight metal having favorable weight to strength properties. In the process, approximately two tons of alumina, plus considerable electric power, and indirect use of alkali are used to produce one ton of cell grade, commercial aluminum.

Alumina is currently produced almost exclusively from bauxite, a mineral that contains from 50 to 60 percent alumina plus silica, moisture and other metal oxides. Because the United States has only a limited amount of bauxite, which is low grade, it imports cell grade alumina and bauxite from Jamaica and increasingly from Australia, Boke (New Guinea), Brazil, and Guyana. Together these imports account for about 95% of domestic alumina consumption.

Direct manufacturing costs for domestic alumina appear to be in the range of $170-$200 per short ton at this time. However, the price of imported bauxite is about $50 per short ton higher due to the effect of a tax levy on bauxite by the International Bauxite Association (IBA).

The U.S. alumina production is located in the South and Southwest, close to energy sources, raw materials and low cost (ship/barge) transportation. However, this has placed the alumina plants at a considerable distance from the bulk of the lower-cost primary aluminum smelter capacity, located in the Northwest. Because of rapidly rising energy costs, the aluminum production costs in the Southwest and the TVA area are increasing faster than in the Northwest where the great portion of the electrical power is from hydroelectric sources. Exhibit 4-2 shows the location of the current U.S. alumina plants and the primary aluminum sites.

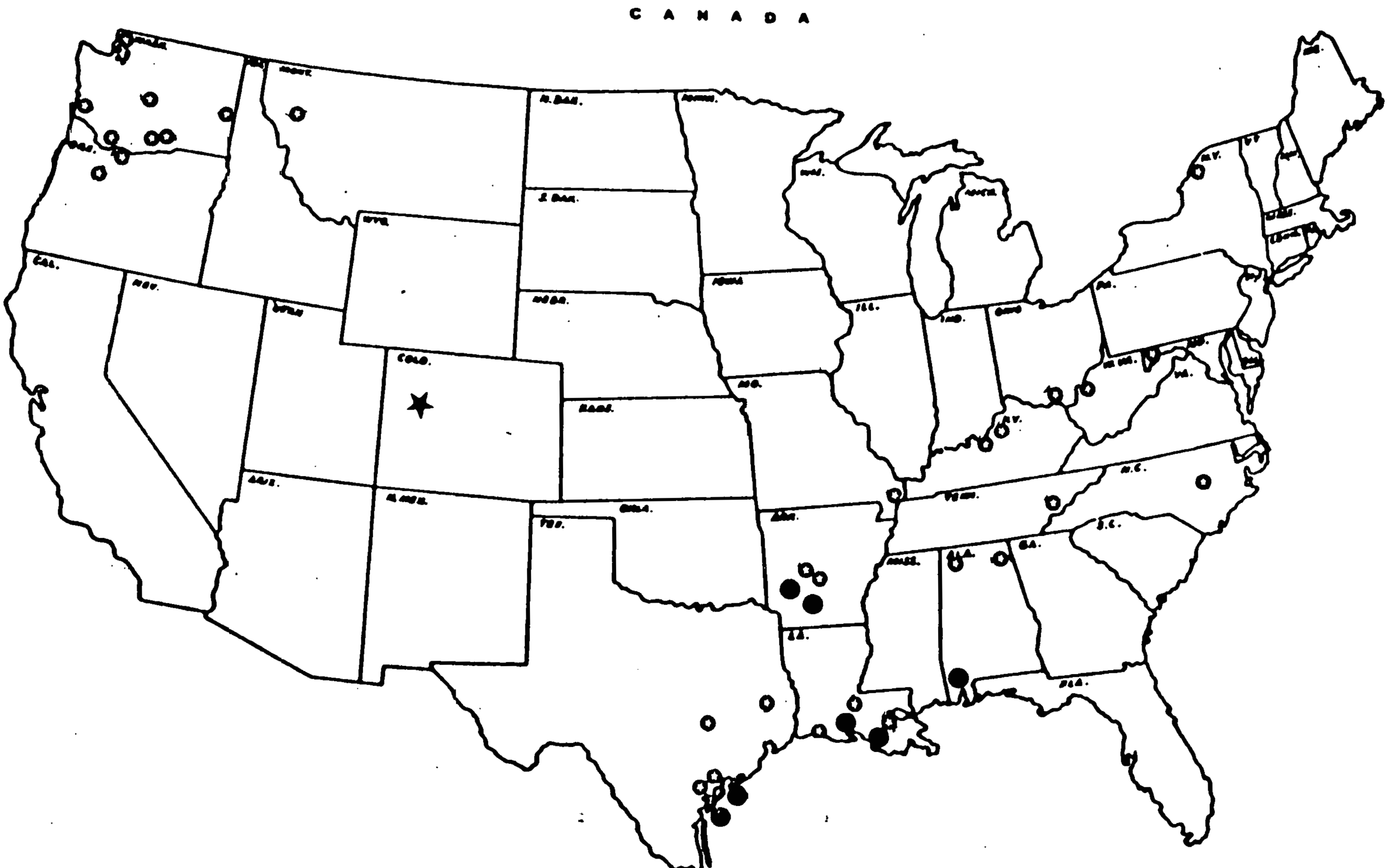
Because freight is such an important component of aluminum economics, alumina sources located closer to the Northwest smelters, could have a significant economic advantage, on the order of $10 to $20 per ton over existing domestic alumina plants.

Beyond being an important industrial commodity, aluminum is widely used in airplanes and motorized vehicles, thus being an essential national security commodity. During World War II, considerable investigation was aimed at examining the potential of non-bauxitic sources of alumina, particularly alunite and kaolin clay, in case Jamaican or South American bauxite supplies were interrupted. Since that time the U.S. has become even more dependent on imported sources for alumina relying on imports for 95% of its supplies of alumina or its raw material, bauxite.

In 1978, the U.S. imported or produced from imported bauxite approximately 10 million short tons of alumina, at a rate of production that has been growing at approximately 2 percent per year. With the increased emphasis on reduced weight in automobiles and containers, this rate of growth may well accelerate. Even at a 2% growth rate, however, alumina demand will exceed 14 million tons by the end of this century, with imports having to account for nearly all of the increase.

Exhibit 4-2

U.S. ALUMINA AND PRIMARY ALUMINUM PLANTS



It is estimated that the northern section of the Piceance Basin contains 6 to 7 billion tons of alumina equivalent as dawsonite, a potential source of alumina that is intermingled with the kerogen and other minerals recoverable as part of the mining for shale oil. The primary issues are:

- Can this be accomplished economically, particularly in co-product (or joint product) facilities?
- Are there adequate markets to absorb these new supplies?

The study of the market potential for alumina focused on these issues by examining the following questions:

- What is the projected market demand for alumina?
- What are the current and potentially competing sources of supply and how will these change?
- What will be the market value for alumina and how will this be determined in the future?
- Are there any institutional or other barriers that will limit entry to the market?

2. Market Demand for Alumina and Aluminum

Primary Aluminum Markets -- Domestic. U.S. consumption of alumina is almost entirely a function of the demand for primary aluminum. This primary metal has four major end use markets:

- construction
- transportation
- electrical
- containers

Smaller amounts of aluminum, each representing less than 10% of demand, are used for appliances, equipment and marketing.

The history of domestic consumption by these major end use markets from 1969 to 1977 is summarized below in thousands of short tons:

Domestic Aluminum Demand
(Thousands of Short Tons)

End Use Markets	1969	1977	% Annual Growth in Tonnage
Construction	990	1,340	3.9
Transportation	830	950	1.7
Electrical	600	620	0.4
Containers	500	1,148	10.9
Other	1,190	1,320	1.4
Total	4,110	5,370	3.4

Source: Mineral Commodity Profile, Bureau of Mines

Construction applications are primarily in the form of extrusions used in window frames, panels and other building components.

Transportation markets consist of automobile engines and parts, and are specially affected by the desire of auto makers to reduce vehicle weight and improve fuel efficiency, particularly in heavy-duty vehicles such as trucks and buses.

While electrical markets are sizeable, there are few new applications available for long haul transmission lines, the primary electrical use of aluminum. The domestic home wiring market has been essentially eliminated as a growth application because of potential safety problems.

Container usage of aluminum, especially for beer which is shipped considerable distances, represents a large and growing market. The major competitors to aluminum in the individual serving size beer and soft drink markets are glass bottles, PET resin containers and steel cans. However, because of a combination of changing technology and economics, it appears that the future container markets are likely to be largely aluminum and glass.

The appliances, equipment and machinery and other end use markets represent relative small and slow growth markets.

New Markets for Aluminum and Alumina. Chemical uses of alumina are primarily aluminum fluxes (cryolite) required for production of aluminum. This accounted for about 50% of all alumina not directly used as cell feed for aluminum.

Aluminum trihydrate, the initial alumina plant process output, has a growing market as a fireproofing agent for textiles, but it is still an insignificant demand in comparison to primary aluminum.

One of the potentially major new uses for alumina may result from development of FRM (Fiber Reinforced Metal) based upon imbedding Alpha Aluminum Oxide in a metal matrix such as magnesium or aluminum. The potential exists for such composites because of their high stiffness and strength to weight ratios to displace both steel and FRP (Fiber Reinforced Plastics) from auto body components.

Projection of Future Market Demand. The projection is that domestic aluminum production will increase at a rate of 2% per year, below historic demand growth rates. The primary impediment will be lack of sufficient, low-cost sources of hydroelectric energy for new aluminum smelters. The difference between demand and domestic supply will need to be met from imports of aluminum, potentially from new facilities being planned for Western Canada, a future hydroelectric area. It seems likely that shale oil (dawsonite) based alumina can capture this market growth as well as displace a portion of the current, outmoded domestic plants linked to imported, high cost bauxite.

The projected future demand for alumina co-production is based on the market projections shown below:

- Domestic aluminum smelting capacity will grow at 2% per year, primarily in the Northwest; co-product alumina will be able to capture all of this growth; given a current base of 10 million tons per year, 2 million tons of additional alumina will be required every ten years.

- The current domestic alumina production capacity for processing imported and domestic bauxite to alumina is over 40 years old and will need to be fully replaced or substantially remodeled in the next 30 years; shale co-product alumina will eventually be able to replace up to 40% of this capacity; given the current base of 6.6 million tons per year, 3 million tons of current production may be replaced by shale co-product alumina by the year 2010.

- Imports of alumina in 1978 were 4.5 million tons, primarily from Australia; if shale co-product alumina could ultimately capture 20% of this market as foreign alumina production facilities become obsolete, this could provide a demand for 1 million tons per year of shale co-product alumina by the year 2000.

- U.S. alumina exports currently are 1 million tons per year; given that world aluminum production has been growing at over 5% per year there is a rapidly growing international market for alumina; in addition, U.S. consumption of aluminum, growing at 4.2% per year will continue to outstrip domestic aluminum production capacity, growing at 2%, (since 1970 the U.S. has become a net importer of aluminum of over 0.5 million tons in 1979). Since a considerable portion of new world aluminum smelting capacity is being planned for Canada, it seems likely that the U.S. shale co-product alumina could readily compete for this growth market of up to 2 million tons of additional alumina every ten years.

The results of these analytic assumptions on the size of the future shale co-product alumina market are summarized below:

Projected Markets for Shale Co-Product Alumina
(Millions of Short Tons per Year)

Year	Growth in Domestic Aluminum Demand	Replacement of Alumina Plant/Imported Bauxite	Displacement of Imported Alumina	New Exports	Total
1990	2	1	-	0-2	3-5
2000	4	2	0-1	0-4	6-11
2010	6	3	0-1	0-6	9-16

The first two markets, the growth in domestic aluminum production and the replacement of out-moded alumina plants linked to imported bauxite, appear to be likely events. However, the displacement of imports of alumina and the capture of new exports require more extensive international trade agreements and thus are shown as a range in terms of their projected future markets.

3. Supply of Alumina and Aluminum

Aluminum production is dominated by a relatively small number of industrialized nations such as Canada, with large consuming industries such as aircraft or low cost energy. When U.S.S.R. reported aluminum production is excluded, five nations account for 54% of the world cell grade alumina demand, as shown below:

Ranked Major Primary Aluminum Producing Nations
(Thousands of Metric Tons)

Nation	Region	1970	% World	1978	% World	% Annual Production Change
U.S.	N. America	3,608	37.4	4,358	30.0	2.4
U.S.S.R.	E. Europe	1,100	11.4	3,248	15.1	8.0
Japan	Asia	733	7.6	1,058	7.3	4.7
Canada	N. America	973	10.1	1,049	7.2	0.9
W. Germany	W. Europe	309	3.2	740	5.1	10.6
Norway	W. Europe	503	5.5	657	4.5	2.7
Other	-	2,393	24.8	4,470	30.8	8.1
Total		9,646	100.0	14,532	100.0	5.2

Source: World Bureau of Metal Statistics; Minerals Yearbook, Bureau of Mines

World alumina production, however, is not distributed in the same manner. Alumina plants are typically located on water or proximate to bauxite mines to reduce the freight costs, since 2.6 tons of bauxite are used on average, per ton of alumina. The effect is to locate smelters in user countries and alumina plants in bauxite producing regions. When the bauxite supplying nations such as Jamaica and Guyana embarked upon a policy of acquiring more of the value added income for bauxite by means of taxation, alumina production capacity began to change significantly, as shown below:

Ranked Major Primary Alumina Producing Nations

(Thousands of Metric Tons)

Nation	1970	%	1978	%	% Annual Production Change
Australia	2,139	10.3	6,659	26.4	17.6
United States	6,486	31.3	6,033	24.0	(1.0)
U.S.S.R.	1,815	8.8	3,350	13.3	9.2
Jamaica	1,690	8.2	2,064	8.1	2.8
Japan	1,285	6.2	1,785	7.1	4.8
West Germany	758	3.7	1,459	5.8	9.8
Other	6,528	31.5	3,854	15.3	(7.2)
Total	20,701	100.0	25,186	100.0	2.8

Source: Metals Bulletin, Minerals Yearbook, Bureau of Mines

Australia became the dominant supplier of the free world bauxite and primary alumina needs, but it is gradually shifting its emphasis toward upgrading to metal. At the same time, the United States actually experienced a reduction in alumina production. Australia furnished 75% of all U.S. alumina imports in 1979, so the U.S. is vulnerable to interruptions of a basic raw material required for aluminum production.

World alumina trade is largely internal between individual primary aluminum producers or consortia. Because alumina is not truly an open market commodity, foreign trade does not exist in the commercial sense. A table showing an estimate of U.S. imports of alumina between 1970 and 1979 is shown below:

U.S. Trade in Alumina 1970-1979
(Thousands of Short Tons)

Item	1970	1979	% Annual Change
Imports	2555	4520	8.5
Exports	1024	967	(0.6)
Net Imports	1531	3553	14.7

Source: Mineral Industry Survey, Minerals Yearbook; Bureau of Mines

Imported alumina and its predecessor ore, bauxite, furnish the great preponderance of U.S. supplies for manufacture of primary aluminum. The principal reason for this is that domestic ores have a high silica content which is costly to remove by the lime-sinter process. The history of U.S. alumina and bauxite sources is seen in the next table:

U.S. Supply of Alumina and Bauxite by Source
(Thousands of Short Tons)

	Supply	1970	1978	% Annual Change
Bauxite for Alumina	Domestic	1,924	1,597	(7.0)
	Net Imports	14,488	13,383	(1.0)
	Total Supply	16,412	14,980	(1.1)
Alumina	Domestic Prod'n	7,148	6,568	(1.1)
	Net Imports	1,531	3,404	10.5
	Total Supply	8,679	9,972	2.0

Source: Mineral Industry Survey, Minerals Yearbook; Bureau of Mines.

4. Market Value for Alumina

Because of foreign tax levies and geographically widely different energy costs, the future market value for alumina will be both a function of aluminum prices and changes in the manufactured cost of alumina.

a. Manufactured Cost of Alumina from Bauxite. The primary means for converting bauxite to alumina is through the Bayer Process, a process that involves physical grinding, pressure digestion, chemical precipitation, and finally calcination. While labor is the largest single component of direct costs, the raw material (bauxite) and energy costs account for large shares, as shown below:

Direct Cost Item	% of Total Direct Costs
• Labor	45%
• Raw Materials (Bauxite)	28%
• Energy	17%
• Other	10%

The 1980 manufactured cost of alumina can be estimated through engineering costing by defining the inputs and unit costs, as shown on the following page. This calculation assumes that the cost of energy needed in the manufacture of alumina will be equal to the current world price of crude oil or $5 per million BTU.

Imputed Domestic Alumina Direct Production Costs
($/Ton)

Cost Item	Units	Requirements	Unit Costs	Estimated 1980 Cost/Ton of Alumina
Bauxite	Short Tons	2.4	$14.80	$35.52
Limestone	Short Tons	0.74	$4.00	0.30
Soda Ash Equivalent	Short Tons	0.75	$107.00	8.03
Starch	Short Tons	0.01	$180.00	1.10
Electricity	kWHr	71	$0.05	3.55
Steam	Short Tons	1.35	$10.00	13.50
Natural Gas	Mcf	4.9	$5.00	24.50
Water	Thous. Gal.	4.7	$0.50	2.35
Labor	Man-hours	5.6	$10.00	56.00
Total - Direct Costs Only				$144.85

Source: Cost Estimate of Bayer Process for Producing Alumina, Peters, Johnson & Kirby, Bureau of Mines

Added to these costs would be a charge of 10% to 25% for fixed and indirect costs including depreciation, plus a charge of 15% to 20% for interest, taxes and anticipated profit.

For imported bauxite, the labor costs are generally lower but the transportation and tax levies (in Jamaica) would be considerably higher.

Taking these into account, the estimated manufactured cost of bauxite is approximately $200 per ton. For comparison, a projected alumina plant in Bintan, Indonesia, reported estimated costs of

$225/metric ton FOB, while Japan reported an ability to purchase at $180 per ton not including freight charges. Market prices in the U.S. of competitive material would include a $50 to $60 per ton IBA tax levy that would revise the total to $220 - $260 per ton. These costs are summarized below:

Cost Items	Effect on Market Price ($/Ton; 1980 $)
• Direct Production Costs	$145
• G & A (15%)	$ 20
• Depreciation (0%-10%)	$0-$15
• Interest, Taxes & Profit (5%-15%)	$5-$20
Subtotal	$170-$200
• Jamaican Tax Levy on Bauxite	$50 -$60
Total	$220 - $260

b. Value of Alumina Based on Aluminum Prices. Alumina represents 12.3% to 12.9% of the primary metal price, as determined from studies in 1970 and 1977 by the Bureau of Mines. If this relationship were to hold for 1980, the imputed value of alumina, given a current spot price of $0.76 per pound (ingot), or $1,520 per short ton, would be approximately $187 to $196 per short ton. This figure is consistent with the above manufacturing cost calculation and with other reported values for long term alumina offerings to Japanese smelters.

The future price for alumina will reflect inflation, real cost increases in energy, cost increases due to aluminum scarcity and increases in tariffs and taxes. Assuming only a 2% real increase in energy costs, the imputed market value of alumina in the future is as follows (in 1980 dollars per ton):

- 1980 -- $220-$260
- 1990 -- $230-$270
- 2000 -- $240-$280
- 2010 -- $250-$290

These values for alumina are not necessarily representative of what would be used by an integrated producer of primary metal, since they would have some discretion in how they allocate costs to the different production stages. It has a great deal of significance, however, to non-integrated smelters, or to ones with more smelter capacity than captive alumina supplies who must purchase their alumina.

The Market Potential for Soda Ash

1. Introduction

Soda ash is one of two basic sodium oxide sources, the other being sodium hydroxide (caustic soda). Soda ash is the carbonate form of sodium oxide, while caustic soda is the hydroxide. Soda ash is a dry, granular product of about 60 lb/cf density and available naturally from trona mines or manufactured using the Solvay process. Caustic soda is produced as an involuntary co-product of chlorine in the ratio of 1.1 tons/ton of Cl_2.

Caustic soda and soda ash share some markets, but caustic cannot replace soda ash in its major market, glass. Soda ash can replace caustic in several of its end uses, especially the Bayer Process for alumina manufacture and kraft pulp production.

U.S. soda ash end uses are primarily for glass (50%), inorganic chemicals (25%), water treatment and other miscellaneous uses. New potential uses include lime-sinter recovery of alumina, sodium thiosulfite production for thermomechanical pulp bleaching, and recovery of heavy metals from effluents.

Domestic production of soda ash and caustic soda was approximately 10 million tons each in 1978. World production of soda ash and caustic soda was approximately 30 million tons each in 1978. Any significant drop in involuntary caustic supplies with respect to demand as a consequence of disruptions in markets for chlorinated derivatives would provide substantial potential for new soda ash markets.

Domestic soda ash is currently provided from trona mines, a natural source of soda ash. It is unlikely that shale oil based soda ash will be able to displace any of this production. Moreover, it is likely that trona and dawsonite based soda ash will share future growth in market demand. U.S. soda ash and glass plants are shown on Exhibit 4-3.

The major opportunity for growth in soda ash demand appears to be the international market. Eastern Europe exports large quantities of soda ash to Western Europe, albeit at greatly discounted prices. Should East European production be blocked, become uneconomic or be unavailable because of production disruptions, it is possible that much of that market could become available to U.S. production. In addition, European and Japanese soda ash is produced by the Solvay Process, the most costly world source accounting for approximately 60% of world capacity. Trona and oil shale based soda ash are lower cost alternate sources and could favorably compete in West European and Asian markets absent any market barriers.

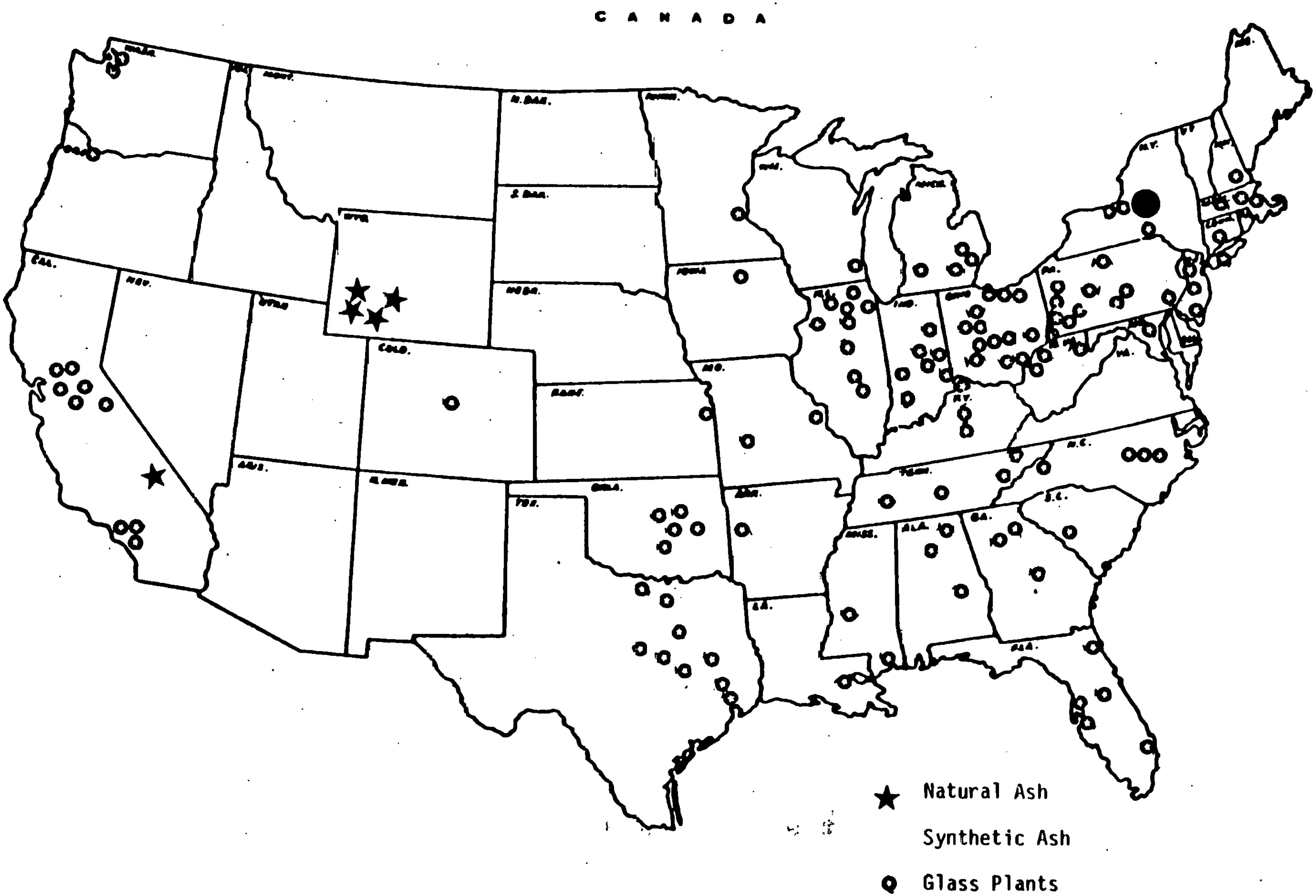
2. Market Demand for Soda Ash

The major domestic uses of soda ash are for glass, chemicals and a variety of other smaller uses. The glass market by itself represents over one-half of soda ash demand. Typically, each pound of glass requires about 0.25 pounds of soda ash, reduced to sodium oxide (Na_2O). Because of the low weight to volume ratio of glass containers, freight costs are a critical consideration, and glass plants are located close to markets and raw materials.

Market Demand for Glass. Domestic production of glass has grown at an annual rate of 2.9% for the past 10 years. Assuming the various glass types have the average Na_2O specified, nearly 5 million tons of soda ash was consumed for glass manufacturing in 1979, as shown in the following table.

Exhibit 4-3

U.S. SODA ASH AND GLASS PLANTS



Imputed Soda Ash Consumption in Glass by Type, 1979

Glass Product	% Sodium Content	Production (M Tons)	Soda Ash Equivalent (M Tons)
Containers	15.0	23,415	3,470
Flat Glass	15.0	3,430	890
Fiber	12.0	1,970	410
		28,815	4,770

Source: Considine: Glass Manufacture

Containers constitute the largest single market for glass and indirectly for soda ash. The glass container market in 1970 and 1979, expressed as the weight of glass required for different products, is as follows:

Domestic Glass Container Shipments by Product Type and End Use (M Tons)

Type Container	End Use	1970	1979	% Annual Change
Narrowneck	Sub-Total	8,865	10,645	2.1
	Food, Health, Chemical and Toiletry	2,165	2,000	(0.9)
	Beer and Beverage, Returnable	1,055	590	(4.9)
	Beer and Beverage, Non-Returnable	4,325	6,035	(4.4)
	Liquor and Wine	1,320	2,020	4.9
Widemouth	Subtotal	2,285	2,770	2.2
	Total	11,515	13,415	2.1

Source: Current Industrial Reports, Bureau of Census

Glass has actually increased its share of beverage container markets between 1970 and 1979, and it would appear that much of the displacement of glass by plastics has already occurred. Future growth is likely to be at a one to two percent per year rate, or about equal to real GNP. Other markets for glass, particularly for flat glass and fiber glass, have grown much more rapidly to over 10% per year since 1970, and are likely to continue this growth, subject to availability of construction funds.

Market Demand for Soda Ash Chemicals. Chemical markets for soda ash are only half that of glass and also characterized by a significant amount of forward integration. In terms of volume of production, the largest product group is phosphates, followed by silicates, bicarbonate of soda and chromates. In addition there are a large number of minor products such as bisulfites and other salts, which in aggregate amount to about 10% of the inorganic sodium oxide markets.

The production history of the major chemical end uses of soda ash for the years 1970 and 1978 were as follows:

Production for Major Sodium Oxide Chemicals for 1970-1978 (M Tons)

Class	Chemical	1970	1978	% Annual Change
Phosphates	Trisodium	53	64	2.1
	Metaphosphate	45	41	(0.1)
	Pyrophosphate	78	73	(1.9)
	Tripolyphosphate	1,208	752	(5.1)
Sodium Silicate		889	776	(1.5)
Sodium Bicarbonate	Bicarbonate	143	N.R.	-
Sodium Chromate		154	168	1.0

Source: Current Industrial Reports, Bureau of Census

The largest single use of phosphates is as a component in soap or detergent mixes, for industrial and home use.

Projection of Future Market Demand. The future market projection is that domestic soda ash (and sodium oxide) markets will grow at about 2 percent per year while international markets will grow at 4 percent per year. The three greatest uncertainties in assessing the demand for shale oil co-product soda ash are:

- The rate of growth in domestic trona mining in response to perceived demand.
- The extent of access to world soda ash and sodium oxide markets by U.S. exports.
- The future demand for chlorine (and chlorinated products) whose manufacture produces involuntary caustic soda.

In light of these uncertainties, the assessment for co-products assumes that the primary market will be the growth in West European and Asian (Japanese and Australian) sodium oxide markets, and the eventual displacement of Solvay Process soda ash in market economies. Should Solvay Process plants in the COMECON countries also be displaced, the potential market for U.S. soda ash could be substantially greater. More speculative markets involve capture of a portion of the domestic growth market for sodium oxide, and the substitution of soda ash for caustic soda as chlorine demand fluctuates or declines. Further details on each of these future markets is provided below:

- West European and Asian soda ash demand is projected to grow at 2% per year and caustic soda demand at 4% per year. Shale co-product soda ash will be able to capture one-half of the soda ash market growth in these two areas, and one-half of the caustic soda demand growth. Given a current base of 9 million tons per year of soda ash and 8 million tons per year of caustic soda in these markets (and that 1.3 tons of soda ash is required for every ton of caustic soda), 3 million tons of additional soda ash will be required every ten years.
- The current Solvay Process capacity in Western Europe and Asia is about 10 million tons per year. Because of high energy costs, shale co-product alumina and natural soda

ash (from trona mining) will be able to displace this capacity as these plants are phased out by the year 2010. Shale co-product soda ash will be able to capture one-half of this market or 5 million tons per year by 2010.

- Domestic soda ash and caustic soda production has grown at about 1 percent per year; given a sodium oxide pool of 12 million tons per year, 1.2 million tons of additional sodium oxide will be required every ten years, which is equivalent to 2 million tons of soda ash. However, because trona mining would view this as a prime growth target, only a maximum of one-third of this new market is assumed available for shale co-product soda ash.

- Should world chlorine demand decline, in light of a slowing demand for PVC and lead anti-knock compounds, the production of involuntary caustic soda will decline. While this is a highly speculative outcome, it is possible that as much as a 10% decline in chlorine demand and caustic soda production could occur in the U.S., Japan and Western Europe; given a caustic soda base of 18 million tons per year, and the need to substitute soda ash for caustic at a 1.3 to 1 ratio, this represents a 2 million tons per year market, likely shared equally by co-product soda ash and trona mining.

- Finally, numerous new uses for soda ash are being pursued -- for insulation materials, recovery of yellow cake from uranium or and for recovery of tailings in alumina production; these new uses, while speculative, could provide a market for co-product soda ash of 1 million tons per year by the year 2000.

The results of these analytic assumptions on the size of the future shale co-product soda ash market are summarized below:

Projected Markets for Shale Co-Product Soda Ash

(Millions of Short Tons per Year)

Year	Growth in W. Europe and Asian Markets	Replacement of European and Asian Solvay Process	Domestic Growth	Replacement of Caustic Soda	New Markets	Total
1990	3	1	-	0-1	-	4-5
2000	6	3	0-1	0-1	0-1	9-12
2010	9	5	0-2	0-1	0-1	14-18

3. Supply of Soda Ash

Soda ash is commercially produced by the Solvay Process, by mining of trona and by recovery from lake brines. World production of soda ash is primarily from the Solvay Process, while natural soda ash from trona has captured eighty percent of the market in North America. Reported capacity for soda ash by major producing regions is shown in the table below:

Reported World Soda Ash Production Capacity
by Process and Selected Region - (M Tons)

Region	Process	Capacity	%
North America	Solvay	1,900	5.2
	Trona	7,200	19.7
	Lake Brines	1,500	4.0
Sub-Total		10,600	28.9
South America	Solvay	650	1.8
Western Europe	Solvay	8,670	23.7
Eastern Europe 1/	Solvay	11,600	31.7
Africa	Lake Brines	370	1.0
Asia 2/	Solvay	4,710	12.9
Total, all processes		36,600	100.0
	Total Solvay	27,530	75.2
	Total Trona	7,200	19.7
	Total Lake Brine	1,870	5.1
		36,600	100.0

1/ Includes USSR

2/ Includes Japan, Taiwan, South Korea, India, Pakistan, Peoples Republic of China

Source: East/West Trade in Chemicals, OECD 1980; Mineral Commodity Profiles, Bureau of Mines; Bank of Tokyo.

The greatest gross addition to soda ash production capacity has been made in the U.S., where new trona mining plants have not only captured the growth in demand but have also replaced all but one of the previously operating Solvay Process Plants.

Reported capacities for selected producing nations are as follows in 1973 and 1979:

Reported Soda Ash Production Capacity for Selected Producing Nations Ranked by Economy (M Tons)

Nation	Economy Type	1973	1979	% Annual Change
United States	Market	8,300	9,600	2.5
France	Market	1,800	2,000	1.8
West Germany	Market	1,750	2,000	2.3
Japan	Market	1,600	1,500	(1.1)
United Kingdom	Market	1,500	1,800	3.1
Other Market	Market	4,780	6,590	5.1
Sub-Total Market	Market	19,730	23,490	3.0
USSR	Managed	4,520	6,000	4.8
Peoples Republic of China	Managed	1,500	1,500	-
Romania	Managed	1,500	1,500	-
Poland	Managed	850	900	0.9
Bulgaria	Managed	350	1,700	30.5
Other Managed	Managed	1,380	1,510	1.4
Sub-Total Managed		10,100	13,110	4.4
Total		29,830	36,600	3.5

Source: Minerals Commodity Profiles, Bureau of Mines

Soda ash production has increased at an annual rate of 3.4 percent between 1970 and 1978 as set forth in the table below:

Region	1970	1978	% Annual Change
North America	7,770	9,250	2.0
South America	180	370	9.4
Western Europe	6,500	7,160	1.2
Eastern Europe	6,500	10,33	5.9
Africa	165	210	3.1
Asia	2,980	4,000	3.4
Total	24,095	31,320	3.4

Source: United Nations Statistical Yearbook;Bureau of Mines Mineral Commodity Profiles

Eastern Europe experienced the greatest increase in production with much of this production exported to Western Europe, with adverse effect upon pricing. Current West European prices for soda ash are $124 per ton, close to the direct operating costs for the Solvay Process.

Most of Eastern Europe's plants have been built within the past six years, whereas West European and Japanese plants largely predate World War I as part of the original Solvay Process Syndicate. Although the plants differ greatly in age, their process economics are essentially the same.

4. Market Value of Soda Ash

a. Manufactured Costs Pricing. For soda ash, the assumption is that the commodity selling price will be based on manufacturing and basic materials costs. However, for exports of soda ash, these production cost based prices will need to be adjusted for any protective tariffs imposed by importing nations.

Internationally, the manufacturing costs for soda ash are based on Solvay Process economics, a very energy intensive process, as shown below:

Direct Cost Item	% of Total Direct Costs
• Fuel and Power	81%
• Labor and Maintenance	8%
• Raw Materials and Other	11%

The direct manufacturing costs for soda ash produced by the Solvay process are estimated as follows by major cost items for a 350,000 tons per year plant, assuming an energy cost of $5 per million BTU, which is equivalent to the current market price of about $30 per barrel of crude oil:

Estimated Solvay Process Direct Manufacturing Costs
($/Ton)

Cost Item	Units	Requirements/ Year	Requirements/ Year	Unit Costs	Estimated Costs/Ton of Soda Ash
Labor	Man Hours	135,000	0.38	10.00/hr	3.80
Fuel	MCF	7.17×10^6	19.92	5.00/MCF	99.60
Power	Kwh	22.8×10^6	63.33	0.05/Kwh	3.17
Ammonia	Tons	1,100	0.003	150/Ton	0.45
Brine	Tons	560,000	1.60	3.80/Ton	6.08
Limestone	Tons	444,500	1.27	5.00/Ton	6.35
Maintenance	Dollars	2,900,000	--	--	8.30
Other	Dollars	143,000	--	--	0.41
Total					126.22

Source: Chemical Process Industries, Shreve; Industry

To this would be added indirect costs, such as taxes, administration, capital costs and depreciation, interest and profits.

The above data shows that the direct manufacturing costs of soda ash using the Solvay Process are about $125 per ton. When other indirect and capital charges are added, these costs will be $150 per ton.

The table below shows that the cost of Solvay based soda ash in 1990 (expressed in 1980 $) is estimated to range from $150 to $210 per ton.

The cost of producing soda ash fron trona, however, would be lower since this process is less energy intensive and the mining costs would be comparable with those of shale oil mining. The table below shows that trona based soda ash is estimated to range from $50 to $90 per ton. The mining and upgrading costs from trona are based on the economics of the mining and upgrading of co-product soda ash. Current prices for soda ash in the U.S. are $86 per ton.

Cost Items	1990 Market Price ($/Ton; 1980 $)	
	Trona	Solvay
• Direct Production Costs*	40-60	125-150
• G&A (15-20%)	5-15	20-30
• Depreciation (0-10%)	0-5	0-15
• Interest, Taxes & Profit (5-15%)	5-10	5-15
Subtotal	50-90	150-210

*Assumes mining costs of $5 to $10 per ton and upgrading costs of $35 to $50 per ton in 1990, expressed in $ 1980.

Because of these already high and rapidly rising energy costs, the Solvay Process no longer competes in the U.S. with trona based production from the Green River, Wyoming mines. European and Asian Solvay plants are essentially in the same posture as U.S. facilities were ten years ago, so that market substitution of lower cost soda ash sources is likely.

U.S. trona based production capacity is being increased rapidly, and has the potential to increase still further with only incremental expenditures. Vigorous efforts are being made by several potential producers to commercially develop solution mining as a means to reduce mining costs and manpower needs. However, even with current operating practices, soda ash from trona mining is substantially less than the costs of the Solvay Process. The limiting case for trona is boiler capacity. Virtually all new Wyoming facilities are now coal fired so that energy costs, unlike Solvay Process plants, are modest and likely to remain so.

b. Market Value Pricing. Current quotations of prices for soda ash, sodium oxide and caustic soda are shown below, in $ per ton*:

Geographical Area	Light Soda Ash ($58\%\ Na_2O$)	Sodium Oxide ($100\%\ Na_2O$)	Caustic Soda
• United States	86	148	160-200
• Western Europe	124	214	261
• Japan	222	384	283

* All prices are FOB works (e.g., exclude freight costs).

c. <u>Estimate of Future Prices</u>. In the U.S., future market prices for soda ash will be governed by the economics of trona mining. As a result, the market price is expected to only increase slightly over inflation, primarily due to real price increases in the cost of energy.

The future prices in the export market, while more difficult to estimate, are likely to be much higher. The current plant gate price for soda ash is $124 per ton in Western Europe and $222 per ton in Japan. The market price in Western Europe is depressed because of large COMECOM exports of soda ash to Western Europe. However, COMECOM soda ash production is based on the Solvay Process, and as these countries begin to fully account for full energy costs, the Western Europe prices could begin to approach those of Japan.