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ISSUE PAPER
POTENTIAL FOR BY-PRODUCT RECOVERY
IN GEOTHERMAL ENERGY OPERATIONS

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This document is one in a series of similar documents being prepared for DOE/GHTD on the status of specific issues in expanded geothermal energy development. Each of these documents examines a particular issue and has been prepared as a:

- Internal DOE management tool for geothermal energy planning and decision-making
- Stand-alone document highlighting the major factors involved in assessing and addressing the issue
- Summary of the topic on which a more detailed study can be based.

The objectives of each document are to:

- Define the specific issue and its potential effect on geothermal energy development
- Discuss the current understanding of the issue
- Discuss regulatory and strategic aspects of the issue
- Describe the availability and adequacy of solutions
- Identify further R&D necessary to resolve the issue
- Identify an approach to the conduct of further R&D.

TABLE OF CONTENTS

	<u>Page</u>
List of Exhibits	iv
Acknowledgements	vi
I. SUMMARY	1
II. INTRODUCTION	5
III. PURPOSE OF DOCUMENT	7
IV. SCOPE OF DOCUMENT	8
V. CONCLUSIONS AND RECOMMENDATIONS	11
VI. DISCUSSION	14
(1) Why would the recovery of by-products be an attractive activity in geothermal energy operations?	14
(2) What constituents of geothermal fluids are potentially useful by-products and at what levels are they present?	15
(3) What other potential sources of by-products might there be in geothermal energy operations?	18
(4) Are any materials recovered or recoverable from geothermal fluids?	20
(5) Are any materials recovered or recoverable from other brines or from other relevant sources?	27
(6) What technologies are appropriate for recovering potential by-products and how would their technical requirements fit in with geothermal energy facilities?	37
(7) What quantities and qualities of materials could be produced and are they marketable?	52
(8) What costs are involved with these technologies?	69
(9) How might by-product recovery operations affect the overall economics of geothermal energy development?	71
(10) Are there any legal or institutional ramifications of geothermal by-product recovery?	76

TABLE OF CONTENTS (Concluded)

	<u>Page</u>
(11) What technical and economic problems need to be addressed to establish/improve the feasibility of geothermal by-product recovery?	79
(12) What R&D is being conducted to investigate possible recovery systems?	82
(13) What is the role of DOE's Geothermal and Hydropower Technologies Division in this area?	85
REFERENCES	86
APPENDIX A - RECOVERY TECHNOLOGY DESCRIPTIONS	A-1
APPENDIX B - MINERALS DATA SHEETS	B-1
APPENDIX C - ASSESSMENT OF MARKETABILITY OF GEOTHERMAL BY-PRODUCTS	C-1
APPENDIX D - LIST OF CHEMICAL SYMBOLS AND NAMES	D-1
APPENDIX E - BIBLIOGRAPHY	E-1

LIST OF EXHIBITS

<u>Exhibit</u>		<u>Page</u>
1	Field of Interest in Geothermal By-Product Recovery	9
2	Chemical Species Found in U.S. Geothermal Fluids and Their Concentrations (ppm)	16
3	Status of Recovery Operations Using Geothermal Fluids	21
4	Status of Recovery Operations Using Non-Geothermal Fluids	28
5	Processes Reported in Literature as Used or Applicable for Site-Specific Minerals Recovery From Non-Geothermal Brines	39
6	Processes Reported in Literature as Used or Applicable For Site-Specific Minerals Recovery From Non-Geothermal Brines	42
7	Possible Flowsheet for Geothermal Brine Processing to Recover Minerals	44
8	Production of Pure KCl From Geothermal Brines	45
9	Metal Solubility as a Function of pH	47
10	Solubilities of Metal Hydroxides and Sulfides as a Function of pH	48
11	Wastewater Treatment Processes for Removing Heavy Metals	50
12	Annual Amounts of Recoverable Materials From a Best-Case 50 MWe Plant	53
13	Annual Mineral Values From a Best-Case 50 MWe Plant	56
14	Factors Considered in Determining the Marketability of Geothermal By-Products	59
15	Import and Strategic Considerations for Selected Imported Materials	60
16	Recovery Potential of Geothermal Minerals	62
17	Reported Estimates of Recovery Efficiency and Product Purity for Geothermal By-Product Recovery	63
18	Reported Efficiencies of Control Technologies for Treatment of Specific Constituents From Wastewaters	66

LIST OF EXHIBITS (Concluded)

<u>Exhibit</u>		<u>Page</u>
19	Assigned Efficiencies of Various Treatment Systems for Removing Gross Constituents	67
20	Summary of Estimated Wastewater Treatment Costs	70
21	Reported Estimates of Economic Characteristics of By-Product Recovery From Geothermal Fluids	72
22	R&D/Information Needs in the Area of Geothermal By-Product Recovery	81

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I. SUMMARY

This document identifies and discusses the significant issues raised by the idea of recovering useful by-products from wastes (primarily spent brine) generated during geothermal power production. The physical availability of numerous valuable materials in geothermal brines has captured the interest of geothermal resource developers and other parties ever since their presence was known. The prospects for utilizing huge volumes of highly-saline geothermal brines for electricity generation in the Imperial Valley of California have served to maintain this interest in both private sector and government circles.

There is a long history of commercial minerals recovery from natural non-geothermal brines and from seawater in the U.S. and abroad. Major recovered products have included NaCl, KCl, CaCl_2 , MgCl_2 , Li/Li $_2\text{CO}_3$, Mg, Na_2CO_3 , borax, Br_2 , and I_2 . Prominent locations of brine recovery operations in this country include Searles Lake in California and Great Salt Lake in Utah. It is normal for a number of final or intermediate products to be recovered from a single brine source. For example, the co-recovery of chlorides of Na, K, Ca, and Mg is common.

Although not nearly as common as recovery from other types of brines, mineral extraction from hydrogeothermal fluids is not entirely a novelty. Commercially recovered products reportedly include CO_2 , H_3BO_3 , NH_3 , H_2S , $(\text{NH}_4)_2\text{CO}_3$, NH_4Cl , sodium perborate, manganese borate, NaCl, KCl, and CaCl_2 . All of these materials except the last three chlorides have been recovered from geothermal steam at Larderello, Italy. CO_2 has been recovered in Kenya and in the Imperial Valley of California. Na, K, and Ca chlorides have also been recovered in the

Imperial Valley. None of these recovery systems, with the possible exception of CO₂ in Kenya, is still operating.

Field/pilot-plant investigations to date into geothermal minerals recovery have involved As, SiO₂, NaCl, KCl, LiCl, Li₂CO₃, CaCl₂, and hydroxides of Pb, Zn, Mn, Fe, and Li. Laboratory or feasibility studies have been conducted for Pb, Zn, Ag, Fe, Mn, Li, NaCl, KCl, CaCl₂, Mg, Li, Cs, Rb, and Li₂CO₃. Generally speaking, it is too early to predict the prospects for any of these operations when scaled-up.

Information on the presence, concentration, and recoverability of Au in geothermal fluids is conspicuous by its absence. This is not surprising due to the inclination of holders of such information to consider it proprietary. The only references to gold found in the literature are:

- 2 ppm and 5 ppm Au in geothermal sinters in two sites in New Zealand, 2 ppm, Au in Salton Sea brine (unsubstantiated),
- up to 80 ppm Au in some natural hydrogeothermal precipitates
- a rather vague description of the value of recovering 9 metals (including Au) from Salton Sea brine.

Although a few sources of information on the topics of geobrine characteristics and minerals recovery were not reviewed for this report, additional reliable data concerning Au is not likely to be available.

The supply of fresh water from desalted geobrine for agriculture, river flow augmentation, and other purposes has been the subject of official federal attention for well over ten years. This attention has progressed as far as the field testing of three pilot-plant de-

salination techniques using East Mesa brine. There are no current federal plans to proceed with further work in this area.

The technological feasibility of extracting a variety of components from geothermal or "geothermal-like" brines under certain conditions is well demonstrated or envisaged. However, the economics of any such by-product recovery are heavily dependent on highly site-specific factors associated with brine characteristics, desired end-product quality, producible quantity, product value, market availability and accessibility, cost of recovery operation versus derived income or other economic benefits, technical compatibility of by-product recovery with the geothermal energy system, secondary waste treatment/disposal requirements, etc.

The economic benefits to be derived from by-product recovery cannot at this time be realistically determined. Until preliminary designs for recovery systems are available along with brine characteristics and important energy conversion plant specifications, confident cost estimates cannot be calculated for these systems. Gross values for certain commodities indicate, however, that minerals recovery from at least high-salinity brines bears close examination.

Assuming a "typical" 50 MWe geothermal power plant utilizing high-salinity brine, 14 products theoretically recoverable from the brine have values in excess of \$1 million/year (excluding costs associated with recovery operations or product marketing. A number of these have annual values in the tens of millions of dollars, with a maximum of \$129 million for Rb when recovered as RbCl . However, after taking into consideration of market demand, technological feasibility, competition, and market accessibility, only a handful of them appear

to be promising. Much more detailed engineering and market studies than appropriate for this issue paper would be needed to confidently identify recoverable products with good economic prospects.

As far as actual or potential recovery technologies for geothermal fluids or other brines are concerned, the most common appear to be evaporation-crystallization, chemical precipitation, flotation, and flocculation/seeding. It is usual for two or more techniques to be used to recover a particular material. However, brine evaporation will not be a feasible operation for power plants where spent brine must be injected, preventing the recovery of NaCl and KCl.

II. INTRODUCTION

Geothermal fluids are chemically complex, containing a wide range of constituents derived from interactions between the fluid and rock and from other subsurface chemical and thermal processes. The characteristics of these fluids are very site specific and the types and concentrations of constituents vary considerably. Suspended solids, dissolved solids, dissolved gases, and non-condensable gases are found in these fluids. Generally speaking, the more saline the fluid, the more chemically loaded it is. With TDS levels ranging from a few hundred ppm to a few hundred thousand ppm, it is apparent that the high flow rates needed for power production (typically 40,000 barrels per day) can result in significant amounts of chemicals passing through the plant. In addition, various chemicals could be or are generated through the operation of air emission abatement systems, effluent treatment systems, and corrosion and scale control procedures associated with geothermal energy facilities.

Many of these constituents are potentially useful products in their own right, e.g., heavy metals. The recovery and use/sale of such materials has the potential for any or all of the following benefits:

- Improving the overall economics of the project
- Offsetting the cost of environmental controls
- Reducing the pollution load represented by wastes or otherwise better facilitating waste disposal
- Fulfilling environmental regulatory requirements.

These benefits could conceivably more than compensate for the capital and O&M costs incurred in the by-product recovery operations. The technical feasibility, economic attractiveness, public accept-

ability, and environmental compatibility of such operations will be highly site-specific issues. However, indications are that by-product recovery could, in some cases, enhance the technical and economic characteristics of geothermal energy utilization.

III. PURPOSE OF DOCUMENT

This issue paper was prepared in response to internal DOE/DGHT management needs for a review of available information of interest in the recovery of by-products in geothermal energy operations. The purpose of the document is to:

- Discuss the major technical, economic, and regulatory issues which must be considered in decisions regarding potential by-product recovery
- Describe the progress to date in assessing the feasibility of recovery activities
- Identify information and research needs for a fuller investigation of recovery operations.

The discussions in this report is organized into a question-and-answer format for ease of reading. The types of information needed by decision-makers and others interested in geothermal by-product recovery have been covered in 13 questions, which appear collectively in the Table of Contents.

IV. SCOPE OF DOCUMENT

The potential field of interest in geothermal energy by-product recovery spans a variety of energy, mineral mining, and industrial processes. Exhibit 1 identifies the geothermal fluid applications (energy and non-energy) that by-product recovery could be associated with and the other types of processes that might reasonably be expected to provide data and technology useful for consideration. There is virtually no recent commercial experience with recovery from either spent brines in geothermal energy operations or from geothermal fluids directly. Therefore, it might be advantageous to look at similar types of processes for information which may produce a clearer understanding of the merits and problems of geothermal applications. It should be recognized that treatments to produce more manageable wastes may form the basis of economic by-product recovery.

The focus of this document is minerals recovery operations utilizing geothermal and other natural brines, with some reference to brine-producing solution mining. Processing of mineral ores is not considered, irrespective of whether any brine-type intermediate products are involved. Furthermore, the report concentrates on "direct" constituent extraction from brines rather than brine desalination as a route to by-product recovery, although the water itself may be a useful by-product. This is at least partially because the literature on desalination is copious. However, a specific geothermal brine desalination project in the U.S. is discussed and bibliographic references to potentially relevant literature on the topic of desalination are included in an appendix.

EXHIBIT 1
FIELD OF INTEREST IN
GEOTHERMAL BY-PRODUCT RECOVERY

Brief discussion is made of other (non-brine) potential sources of by-products which might be associated with geothermal energy facilities. However, these sources are not likely to be significant in overall geothermal energy development compared to spent brine.

V. CONCLUSIONS AND RECOMMENDATIONS

The major conclusions/observations drawn from the literature reviewed and people contacted for this document are set out below.

- The concept of by-product recovery from spent brines (and possibly from other wastes) in geothermal energy operations is intuitively attractive. The quantities of a number of brine minerals with known values which may pass through a typical commercial-scale geothermal power plant are sufficient to warrant an examination of the potential economic benefits of their recovery and use/sale. In addition, it is possible that minerals recovery could be used in conjunction with pre-injection brine treatment or, where injection is not required, to help meet environmental waste control regulations.
- A wide range of geothermal fluid constituents could be useful by-products, e.g., Na/K/Ca chlorides, heavy metals, CO₂, SiO₂, Br₂, and B. At present, interest appears to be focussed on Pb, Zn, Ag, and Li. The proprietary nature of information relating to Au and its recovery tends to keep this information out of the open literature and, therefore, little can be concluded about prospects for Au recovery.
- Commercial minerals recovery from non-geothermal brines (inland brines and seawater) and from geothermal fluids have long, though interrupted, histories. Perhaps as many as eight different products have been extracted from geothermal steam at Larderello in Italy. CO₂ has been extracted from shallow geothermal wells in Kenya for making dry ice. Geothermal brines in California's Imperial Valley have been the source of NaCl, KCl, CaCl₂, and CO₂. There are no indications that commercial operations are still underway at Larderello or the Imperial Valley.
- By-product recovery systems which have been or might be used in geothermal energy operations typically incorporate a number of different steps for extracting and "purifying" the desired materials. Evaporation is a relatively common element in brine minerals extraction technology, but the need to inject spent brines at most (if not all) geothermal power facilities will severely restrict the application of evaporation-based minerals recovery techniques; this will virtually eliminate consideration of recovering simple chlorides. Chemical precipitation of heavy metals from geothermal brines has been under investigation by the Bureau of Mines (BOM), with sulfide and hydroxide precipitation techniques being focussed on; BOM is interested in continuing work on the sulfidation process.
- The technological features of potential geothermal by-product recovery systems are not defined adequately for making useful or particularly enlightening cost estimates. The technologi-

cal features and associated costs of recovery systems will be highly site-specific, being influenced by factors including:

- Geothermal fluid characteristics (input and effluent)
 - Specific by-product(s) to be recovered
 - Quantity, quality, value, and marketability of by-products
 - Type of geothermal energy conversion system used
 - "Size" of energy facility (MWe capacity, brine flow rate, financial base, etc.)
 - Need to inject spent brine
 - Regulatory waste treatment and disposal requirements.
- The only federal R&D directed at investigating the recovery of geobrine minerals is being sponsored by the Department of Interior. The Bureau of Mines is studying sulfide precipitation of heavy metals from Imperial Valley brines in the laboratory. BOM has also recovered hydroxide precipitates of heavy metals from a specially-constructed Imperial Valley pilot plant (now dismantled) and has investigated laboratory processes for cleaning up these precipitates (concentrating on Zn). The Bureau of Reclamation (BOR) has tested three pilot-plant desalination systems for geothermal brines and is currently documenting related work to date. The potential supply of fresh water by desalting geobrine for agriculture or other purposes has received attention for many years. However, BOR is not expected to continue effort in this area. The implications of this geobrine desalination R&D for minerals extraction is not known.
 - Notable R&D/information needs on this topic include:
 - Up-dated geothermal fluid characteristics at selected sites
 - "Localized" market studies of specific potentially-recoverable commodities
 - Evaluation of scaled-up laboratory and pilot-plant processes for geobrine minerals recovery
 - Closer examination of generic minerals recovery technologies, assuming that evaporation cannot be used due to the need to inject spent brines
 - Reasonably accurate cost estimates for recovery systems, if only as a relative guide for site-specific studies.

Recommendations for DOE/GHTD consideration are given below.

- While the recovery of minerals from geothermal fluids will not directly increase energy production from the resource, successful salvage of saleable materials will offset the cost of power and may enhance private sector interest in this area. On this basis, it may be advisable for DOE/GHTD to maintain an interest in minerals recovery as an adjunct to geothermal energy development.

- Despite the technical and economic uncertainty of geothermal by-product recovery, DOE/GHTD should maintain a cursory interest in this activity, particularly in terms of information gathering and monitoring of federal and private-sector activities.
- Generally speaking, potential non-energy uses of hydrogeothermal resources for the production of mineral and fresh water are the responsibility of the Department of Interior. GHTD should keep abreast of developments in relevant mining and materials processing programs in the brine desalination programs in the Bureau of Mines and Bureau of Reclamation. This can be accomplished through some sort of information transfer channel.
- Recognizing that such information may be regarded proprietary, it may be useful to contact companies (such as Union Oil Co. and Shell Oil Co.) who have current interests in geothermal energy development and who have apparently dappled in the past with minerals recovery from geothermal brines.
- The legal/institutional implications of commercial minerals recovery and sale in conjunction with geothermal energy production should be studied, especially in terms of the Resource Conservation and Recovery Act and the Toxic Substances Control Act.

VI. DISCUSSION

- (1) Why would the recovery of by-products be an attractive activity in geothermal energy operations?

Many elements or compounds which occur naturally in geothermal fluids are valuable materials in their own right. Although they are usually present in these fluids at fairly low concentrations (measured in parts-per-million), the very large volumes of geothermal fluid required to run a power plant can represent extremely large quantities of these materials on a yearly basis. The value of certain materials in these amounts can be significantly by large to encourage the evaluation of whether any of the materials could be recovered and utilized in a manner benefitting the geothermal energy project.

These benefits could come in a number of forms, as identified below.

- Profit may accrue from the sale of recovered products.
- Monetary income derived from by-product sale may offset the cost of required environmental control systems.
- Ultimate waste disposal may be made easier and/or less expensive by reduced pollution load or other enhanced waste characteristics.
- By-product recovery processes may help fulfill environmental regulatory requirements pertaining to waste disposal.

As a joint engineering and economic venture with thermal energy conversion, by-product recovery would constitute a more complete utilization of the geothermal resource. If cost-effective recovery technologies can be demonstrated, and product marketing arrangements can be established, the economic return from the marketing of geothermal by-products may become an added attractive feature for geothermal energy investment.

- (2) What constituents of geothermal fluids are potentially useful by-products and at what levels are they present?

Geothermal fluids are chemically complex and may contain many constituents. Which species are present and at what concentrations are extremely site-specific factors. The total-dissolved-solids (TDS) concentration of major U.S. hydrothermal-geothermal resource fluids ranges from hundreds of ppm to hundreds of thousands of ppm. Exhibit 2 presents the major chemical characteristics of a number of U.S. resources in order of increasing salinity. Certain chemical species are found in all or most of the fluids at the listed sites, e.g., Cl, Na, K, Ca, Li, F, Mg, B, BiO_2 , H_2S , CO_2 , and NH_3 . This exhibit is not comprehensive in terms of significant U.S. resource sites nor up-to-date in terms of geochemical data. However, it serves to illustrate the wide variation of fluid characteristics from site to site and even at the same site (see, for example, the two fluids from East Mesa: 1,800 ppm TDS versus 26,300 ppm TDS).

In addition to the obviously valuable silver found in a few brines, constituents such as Pb, Zn, Li, As, B, S, CO_2 , SiO_2 , Mg, Br_2 , and I_2 could also be valuable/useful if recovered under the right conditions. The presence or concentrations of gold, which is believed to exist in some resources, are not reported in Exhibit 2; in some cases, this information is considered proprietary and is not openly reported.

A major component of geothermal fluids is, of course, water. The usefulness of water of the correct quality for industrial, agricultural, and drinking purposes is obvious, especially in water-short western states. The desalination of geothermal brines has been tech-

EXHIBIT 2
 CHEMICAL SPECIES FOUND IN U.S. GEOTHERMAL FLUIDS
 AND THEIR CONCENTRATIONS (ppm)

nologically demonstrated in the field. However, the recovery of potable water from geothermal fluids is considered to be largely beyond the scope of this study.

- (3) What other potential sources of by-products might there be in geothermal energy operations?

In addition to planned recovery from the geothermal fluid itself, there may be other materials associated with the energy operations that might yield by-products. The primary ones are:

- Air (primarily H₂S) abatement wastes
- Cooling system make-up treatment and cooling tower blowdown, where the cooling water is not geothermal brine
- Scale deposited in the plant and fluid transport lines.

Of these materials, it is unlikely that anything other than H₂S abatement wastes could constitute a useful source of recoverable products. Although scales at certain sites may contain predominantly one constituent (e.g., silica at Salton Sea), scale deposits will tend to incorporate a large number of chemical substances as impurities; collection and processing of these solid materials to extract certain components is unlikely to be a practicable option.

Sludges generated during the control of H₂S air emissions (where such control is needed) may well be a viable source of sulfur and perhaps other chemicals, depending on the abatement technology used. Elemental sulfur produced by the Stretford Process used at The Geysers is reportedly removed from the site by a party interested in it as a useful product (18). Elemental sulfur is also produced by the Iron Catalyst Process developed at The Geysers (15).

Sulfur-containing compounds generated by other abatement systems may also be of interest. For example, the EIC Process removes, in addition to H₂S, about 80% of the NH₃ and H₃BO₃ from the geothermal steam (15). Techniques for commercial separation and recovery of the

residual $(\text{NH}_4)_2\text{SO}_4$, which is the major component, and the H_3BO_3 are under investigation (12). The EIC Company is reportedly modifying the process chemistry of the EIC abatement system to produce "more valuable by-products" (31 p. 74). There seems to be some disagreement over whether the EIC Process sludge will normally be injected along with cooling water (19) or disposed of as solid waste (12). Whichever is the particular fate may influence the technical and/or economic features of any recovery system.

- (4) Are any materials recovered or recoverable from geothermal fluids?

There appear to be no intentional commercial by-product recovery operations at this time used in conjunction with geothermal energy utilization in the U.S. nor any such current operations elsewhere in the world. However, previous commercial recovery operations, pilot-plant activities, and technical and/or economic feasibility studies have been reported in the literature. For the most part, these studies are very brief and occasionally devoid of significant information, even to the point of failing to identify recovered products. Exhibit 3 summarizes most of the references to actual or possible recovery operations using geothermal fluids identified during the preparation of this report. (For certain items, Exhibit 3 presents all the information available in the reviewed literature.)

There are numerous references to the commercial recovery of a variety of chemicals at Larderello, Italy, but there is no clear agreement concerning the precise range of products recovered or relevant time periods. It does seem, however, that such recovery was begun even before geothermal power production at the site (circa 1905) but is no longer operating. In Kenya, CO₂ has been reportedly extracted from geothermal wells and used for making dry ice for years. The Wairakei and Broadlands sites in New Zealand have long been the subject of mineral extraction investigations, with pilot-plant systems constructed for As and SiO₂ removal. Geothermal brine operations (actual or contemplated) in other countries are also identified in Exhibit 3.

EXHIBIT 3

STATUS OF RECOVERY OPERATIONS USING
GEOHERMAL FLUIDS

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Kenya	¹ CO ₂	Commercial	Used for making dry ice	¹ (1978)
Larderello, Italy	² H ₃ BO ₃ NH ₃ CO ₂ H ₂ S	Commercial	During 1930's	¹ (1978) ⁵ (1981) ⁶ (1978)
	³ Dry ice (CO ₂) NH ₃ (liquid) (NH ₄) ₂ CO ₃ NH ₄ Cl Sodium perborate Manganese borate	Commercial	<ul style="list-style-type: none"> • 1940, 8,000 tons/yr. of boric acid and 4,500 tons/yr. borax • Borax production uneconomic by 1971. 	¹⁷ (1974)
Wairakei, New Zealand	⁴ As	Pilot plant	<ul style="list-style-type: none"> • Iron floc process • Could produce 200 T/yr. 	⁵ (1981)
Wairakei and Broadlands, New Zealand	⁵ SiO ₂	Two techniques at pilot plant	<ul style="list-style-type: none"> • CaSiO₃ precipitation • Fluidized bed SiO₂ precipitation 	⁵ (1981)
Cerro Prieto, Mexico	⁶ KCl	Pilot plant	<ul style="list-style-type: none"> • KCl-NaCl salts from evaporation ponds separated by flotation 	⁵ (1981)

EXHIBIT 3

STATUS OF RECOVERY OPERATIONS USING

GEOTHERMAL FLUIDS

(continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Salton Sea, California (Magmamax and Woolsley Wells)	Pb Zn Ag Fe Mn	Bench-scale laboratory	<ul style="list-style-type: none"> ● Precipitation as sulfides ● U.S. Bureau of Mines/ SRI International 	7 (1980)
Imperial Valley, California	Li	Under Development	U.S. Bureau of Mines	8 (unknown but recent)
Reykjanes, Iceland	NaCl KCl CaCl ₂	<ul style="list-style-type: none"> ● Economic feasibility study ● Planned process plant (17) 		9 (1972) 17 (1974)
East Mesa, California	Water (desalinated)	Pilot plants for 3 systems: multistage flash evaporator, vertical tube evaporator, and electrodialysis unit.	<ul style="list-style-type: none"> ● Desalination system operated by U.S. Bureau of Reclamation CaCO₃, BaSO₄, and SiO₂ scales produced 	10 (1977) 26 (1982)
Tuscan Pools, ?	H ₃ BO ₃	Commercial ?	Recovered since 1700's	5 (1981)
Imperial Valley (Niland), California	CO ₂	Commercial	From high gas-content wells	5 (1981)

*The publication dates of the referenced reports are included for guidance, but it must be remembered that the activity described or information noted may date from much earlier than implied by the publication date.

EXHIBIT 3

STATUS OF RECOVERY OPERATIONS USING
GEOTHERMAL FLUIDS

(Continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Iceland	13 Heavy water	"Investigation"	<ul style="list-style-type: none"> • From steam • Development unlikely due to world oversupply 	5 (1981)
Danakil Depression, Ethiopia	14 Mg	Feasibility study	<ul style="list-style-type: none"> • Geothermal spring with 15% Mg (100X sea-water concentration) • Believed to be profitable 	1 (1978)
El Tatio, Chile	15 Li Cs Rb	Feasibility study		1 (1978)
	16 H ₃ BO ₃ KOH	Theorized		
Salton Sea, California	17 CO ₂	Presume commercial	<ul style="list-style-type: none"> • Used for refrigeration from 1932-1954 • May be same as item 12 	16 (1977)
	18 Other minerals including KCl		<ul style="list-style-type: none"> • Serious but unsuccessful effort in early 1960's. • May be same as item 19 	
Imperial Valley, California	19 NaCl CaCl ₂ KCl	Apparently commercial	<ul style="list-style-type: none"> • Morton International, 1964 - 67 • Basically solar pond evaporation • 95% of product shipped was KCl 	17 (1974)

EXHIBIT 3

STATUS OF RECOVERY OPERATIONS USING

GEOTHERMAL FLUIDS

(Concluded)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Imperial Valley, California	NaCl KCl CaCl ₂ 20	Pilot plant and process design	<ul style="list-style-type: none"> • Union Oil Co. research • KCl primary product • Sequential precipitation (NaCl, KCl, CaCl₂) using evaporators and crystallizers 	17 (1974)
Wairakei, New Zealand	NaCl KCl LiCl 21	"Found to be technically feasible but economically unattractive"	<ul style="list-style-type: none"> • Ion exchange process • Multiple-effect evaporation process 	17 (1974)
	NaCl KCl Li ₂ CO ₃ Borax Rb Cs } possible 22	Laboratory and field tests	<ul style="list-style-type: none"> • Several design problems judged resolvable, but market prices made process uneconomic 	
Imperial Valley, California	Pb Zn Li Fe Mn Al? 23	<ul style="list-style-type: none"> • Pilot plant (recently dismantled) at Niland • Current emphasis on Li recovery 	<ul style="list-style-type: none"> • Precipitation as hydroxides • U.S. Bureau of Mines/Hazen Research/WESTEC 	8 (1981) 25 (1982)

In this country, considerable attention has been focussed on the Imperial Valley geothermal resource area as a source of brine minerals since at least the 1930's (16, 17). The very high salinity of many Imperial Valley brines (on the order of hundreds of thousands of ppm TDS) makes mineral recovery an interesting proposition.

In 1974, two oil companies* operated pilot plants in the 1960's to produce power and extract minerals in the Imperial Valley (17). "The market price of their mineral product [unidentified, but probably chlorides] dropped 50% during this period, and their equipment was damaged by corrosion and deposits of mineral scale. These negative factors caused the companies to withdraw from any further geothermal exploration in the foreseeable future, although they have retained their leases for the future in anticipation that the problems will be resolved" (17 p.3).

Morton International recovered chlorides of Na, Ca, and K from evaporating ponds in the Imperial Valley during the mid-1960's. The NaCl was redissolved and processed (in an unspecified manner) to remove impurities, but 95% of the product shipped was KCl (17).

Union Oil Co. reportedly designed an Imperial Valley pilot plant at one time primarily for extracting KCl in a sequential precipitation process using evaporators and crystallizers that also removed NaCl and CaCl_2 (17).

It also appears that CO_2 has been commercially recovered from Imperial Valley brine and used for refrigeration and possibly other purposes (5, 16).

* Unidentified in the reference, but could be Shell Oil Company and Union Oil Company.

Reports indicate that most, if not all, of these U.S. activities were terminated by the end of the 1960's. Although commercial recovery operations and/or serious attempts to demonstrate cost-effective operations endured for a number of years in California, geothermal mineral recovery seemed to lose its practical appeal. By the mid-to-late-1970's, the technical feasibility of large-scale mineral recovery from U.S. geothermal brines was generally considered speculative and the commercial economics were not believed to be favorable (1, 6, 17). However, the prospect for serious energy development of geothermal resources in the Imperial Valley and consequent availability of tremendous volumes of "waste" brine rekindled interest in by-product recovery. Organizations such as the Bureau of Mines and Bureau of Reclamation have maintained an interest in geothermal by-product recovery for many years. Renewed activity on the part of these bodies of the U.S. Department of Interior are identified briefly in Exhibit 3 and described later in this report in response to the question about current R&D.

BRINES

- (5) Are any materials recovered or recoverable from other brines or from other relevant sources?

Commercial processes for recovering minerals from various types of naturally-occurring brines can be found at a number of locations in the U.S., some of which are identified in Exhibit 4. Minerals recovered from brines in the U.S. include compounds of I, Br, Cl, Na, Li, K, Mg, and Ca (6). These brines include surface brines from lakes, brines withdrawn through wells, and seawater. Whether any of these brines are geothermal brines could not be conclusively determined from the reviewed literature. In addition, information regarding recovery techniques employed at these facilities is not readily available.

Not knowing at what concentrations the recovered materials are present in the brines nor how recovery is effected makes it unadvisable to comment on the applicability of these particular experiences to geothermal energy use. However, Reference 17 states that "technology for treating non-geothermal brines to recover minerals is fairly well developed and available in literature" (p. 14) and that "processes developed for seawater and salt deposit brine mineral extraction should be applicable in extracting minerals from geothermal brines" (p. 6). On the other hand, the very site-specific characteristics of brines will necessitate a specially designed or modified sequence of steps for each application in order to recover the desired material at the optimum efficiency and quality.

EXHIBIT 4

STATUS OF RECOVERY OPERATIONS USING

NON-GEOTHERMAL BRINES

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Woodward, Oklahoma	I ₂	Commercial ¹	2x10 ⁶ lb/yr.	6 (1978)
El Dorado, Arkansas	Br Others (unspecified)	Commercial ²	<ul style="list-style-type: none"> • Several plants • Brine from Smackover Formation 	6 (1978)
Clayton Valley, Nevada	Li	Commercial ³		6 (1978)
Ogden, Utah Ludington, Michigan Freeport, Texas Port St. Joe, Florida	Mg Others (unspecified)	Commercial ⁴	Use lake brines, well brines, and seawater	6 (1978)
Searles Lake, California	Li	⁵	Salt brine lakes	5 (1981)
Smackover Formation, Texas & Arkansas	Li	Research ⁶	From oil field brines	6 (1978)

* The publication dates of the referenced reports are included for guidance, but it must be remembered that the activity described or information noted may date from much earlier than implied by the publication date.

EXHIBIT 4
STATUS OF RECOVERY OPERATIONS USING
NON-GEOTHERMAL BRINES
(Continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
California	NaCl **	Commercial 7	<ul style="list-style-type: none"> • Number of salt producers (Leslie Salt Co., Metropolitan Water District of Southern Ca., Standard Salt Co., Pacific Salt & Chemical Co., Western Salt Co.) • From seawater • Solar evaporation • 35-40 tons/acre 	20 (1975)
Great Salt Lake, Utah		Commercial 8	<ul style="list-style-type: none"> • Solar evaporation • 300-350 tons/acre 	
Wendover, Utah		Commercial 9	<ul style="list-style-type: none"> • Kaisar Chemical Corp. • NaCl is by-product of KCl production by solar evaporation-flotation • Only ~ 4% of 1.2 million tons/yr of NaCl produced is sold 	
Carlsbad, New Mexico		Commercial 10	<ul style="list-style-type: none"> • NaCl is by-product of KCl production by flotation • Most NaCl discarded because market too distant 	
Latin America, Australia, many Asian and African countries		Commercial 11	<ul style="list-style-type: none"> • Solar evaporation of seawater or brines is major source of NaCl 	
Europe		Commercial 12	<ul style="list-style-type: none"> • By-product NaCl from KCl production is marketed in many areas 	

** About 3-4% of total U.S. salt production by mid-1970's produced by solar evaporation.

EXHIBIT 4

STATUS OF RECOVERY OPERATIONS USING
NON-GEOTHERMAL BRINES

(Continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Trona, California	KCl	Commercial ¹³	<ul style="list-style-type: none"> • Kerr-McGee Chemical Corp. • Brine from under dried Searles Lake • Triple-effect evaporation followed by vacuum crystallization and solid-liquid separation • Residual brine and crystallized NaCl-burkeite processed to recover other chemicals (see items 18 and 33) 	20 (1975)
Wendover, Utah		Commercial ¹⁴	<ul style="list-style-type: none"> • Kaisar Aluminum & Chemical Corp. • Brine from just underneath Great Salt Lake Desert • Evaporation pond followed by crystallization pond where sylvinite removed and processed through flotation mill to produce KCl; secondary KCl recovery from washing residual crystals from pond 	
Great Salt Lake, Utah		Commercial? ¹⁵	<ul style="list-style-type: none"> • Two separate operations (Great Salt Lake Minerals & Chem. Co., NL Ind., Inc.) whose major products are not KCl - both based on solar evaporation-crystallization 	

EXHIBIT 4
STATUS OF RECOVERY OPERATIONS USING
NON-GEOTHERMAL BRINES
(Continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Regina, Saskatchewan	KCl	Commercial 16	<ul style="list-style-type: none"> • Kalium Chem., Ltd. • Solution mining of sylvinite from over 5,000 ft., followed by crystallization 	20 (1975)
Sodom, Israel (Dead Sea)		Commercial 17	<ul style="list-style-type: none"> • Solar evaporation of Dead Sea brine followed by solids processing by either decomposition/crystallization or decomposition/flotation • By-products: Br, MgO, HCl 	
Eearles Lake, California	Na ₂ CO ₃	Commercial 18	<ul style="list-style-type: none"> 2 Kerr-McGee processes: • Brine carbonation with boiler flue gas followed by drying/dehydrating • Crystallized NaCl-burkeite from potash production (see item 13) 	
		Commercial 19	<ul style="list-style-type: none"> • West End Chem., Co. • Similar process to item 18 	
		Pilot Plant 20	<ul style="list-style-type: none"> • Occidental Chem. Co. • Solar evaporation and harvesting of 3 different crops of crystalline mixture, one of which will be processed to produce Na₂CO₃ + Na₂SO₄ 	

EXHIBIT 4
STATUS OF RECOVERY OPERATIONS USING
NON-GEOTHERMAL BRINES
(Continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
U.S.A.	MgCl ₂ (Produced primarily as an inter- mediate in production of Mg or MgO)	Commercial 21	<ul style="list-style-type: none"> • Dow Chemical Co. • Uses seawater in production of Mg 	20 (1975)
Norway		Commercial 22	<ul style="list-style-type: none"> • Norsk-Hydro Electrisk • Uses seawater in production of Mg • Process generally as item 21 	
San Diego, California		Commercial 23	<ul style="list-style-type: none"> • FMC Corp. • Artificial evaporation of salt-work bitterns to produce MgCl₂ 	
Great Salt Lake, Utah		Commercial? 24	<ul style="list-style-type: none"> • NL Industries, Inc. • Use residual brine from potash production (see item 15) to produce Mg via MgCl₂ 	
Midland, Michigan		Commercial 25	<ul style="list-style-type: none"> • Dow Chemical Co. • Evaporation and other processing of underground brine to produce MgCl₂ and also CaCl₂ and Br 	
Bristol Lake, California	CaCl ₂	Commercial 26	<ul style="list-style-type: none"> • Produced from brine seeping into excavations of halite mining • Process includes solar evaporation 	20 (1975)

EXHIBIT 4
STATUS OF RECOVERY OPERATIONS USING
NON-GEOTHERMAL BRINES
(Continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
Eearles Lake, California	B (as borax)	Commercial 27	<ul style="list-style-type: none"> • Kerr-McGee • Borax is co-product with Na_2CO_3 at operation in item 18 • Conventional crystallization process, with additional boron recovered by solvent extraction from dilute solution 	20 (1975)
		28	<ul style="list-style-type: none"> • Stauffer Chemical Co. (West End Chemical Co.) • Produced from filtrate from NaHCO_3 cake in Na_2CO_3 production (see item 19). Borax seeding and solid-liquid separation involved 	
U.S.	Br_2	Commercial production ceased in 1969 29	<ul style="list-style-type: none"> • From seawater by "blowing-out" process 	20 (1975)
		Commercial 30	<ul style="list-style-type: none"> • From natural brines by "steam-out" process 	
Israel		31	<ul style="list-style-type: none"> • Dead Sea Bromine Co. • From clarified MgCl_2 brine from KCl plant (see item 17) 	

EXHIBIT 4

STATUS OF RECOVERY OPERATIONS USING
NON-GEOTHERMAL BRINES

(Concluded)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	STATUS OF SYSTEM	COMMENTS	REFERENCES (DATE)*
U.S.	I ₂	Commercial 32	<ul style="list-style-type: none"> From oil well brines by "blowing-out" process similar to Br₂ recovery from seawater From underground brines in Michigan by "blowing-out" process similar to Br₂ recovery from seawater 	20 (1975)
Trona, California	Li	Commercial 33	<ul style="list-style-type: none"> Kerr-McGee Li₂CO₃ produced as co-product from complex brine processing (see item 13). 	20 (1975)
Silver Peak, Nevada		Commercial 34	<ul style="list-style-type: none"> Foote Mineral Co. Li₂CO₃ produced from natural brine by solar evaporation followed by chemical treatment 	
Great Salt Lake, Utah		Planned 35	<ul style="list-style-type: none"> Great Salt Lake Minerals & Chemical Co. Recovery from final bitterns of Great Salt Lake brine solar evaporation 	

As a matter of interest, accessible and potentially-valuable mineral deposits produced by hydrogeothermal processes have been located both on land and off-shore. Examples of geothermal sinters (i.e. residues from evaporation of geothermal brine pools) include:

- silica sinter at Whakarewarewa, Rotorua, New Zealand contains up to 125 ppm Ag and 2 ppm Au
- sinter at Champagne Pool, Waiotapu contains 8 ppm Ag and 5 ppm Au
- and silica sinter at Frying Pan Lake, Waimangu, New Zealand contains 3% W, 3% P, and several percent As (1).

In addition, some naturally produced hydrogeothermal mineral precipitates were found to contain up to 80 ppm gold. Silica precipitate in a drainage channel from a geothermal well in Wairakei contained 100 ppm Au, 100 ppm Ag, 500 ppm Ni, and 500 ppm Cu (33).

Significant amounts of Zn, Ag, Cu, and Pb have been found in metal-rich rocks 250 miles off the coast of Oregon, in 7,000 feet of water (2, 3). USGS discovered these deposits in a seabed area of 6 or 7 hot springs. A USGS chief scientist has been quoted as saying that these deposits could undoubtedly be exploited for their Zn and Ag content if they were on land (2).

In addition, immensely valuable polymetallic sulfide deposits associated with hydrogeothermal processes have been found on the ocean floor in the Galapagos Ridge off the coast of Ecuador. These deposits, which contain Cu, Zn, Ag, Sn, Pb, and V, are believed to be technologically recoverable in spite of being located at a depth of 8,500 feet. The value of these deposits is being discussed in terms of billions of dollars (4).

These features demonstrate the ability of geothermal fluids to produce useful mineral deposits by natural processes. Naturally-

occurring sinters and precipitates (such as those in New Zealand mentioned above) represent mineral residues which could also be obtained by evaporation of geothermal brines. This has implications for the usefulness of evaporation ponds for concentrating minerals in spent geothermal brines after energy conversion, should injection not be required.

To date, there are no publications indicating that the materials of hydrogeothermal origin described above have been processed to produce selected materials.

- (6) What technologies are appropriate for recovering potential by-products and how would their technical requirements fit in with geothermal energy facilities?

A variety of techniques can be employed to remove materials from multi-component process/waste streams. These techniques can be classified as physical or chemical and include:

- Physical processes
 - sedimentation
 - flocculation
 - filtration
 - evaporation/distillation
 - crystallization
 - reverse osmosis
 - flotation
 - air stripping
- Chemical processes
 - chemical precipitation
 - ion exchange
 - electrodialysis
 - leaching

Brief descriptions of the principles of such processes are provided in Appendix A.

In general, a combination of two or more processes is required to obtain the desired product. Virtually all of the processes identified above have been or could be used to extract constituents from various types of brines. Reference 20 provides good process descriptions (including process flowsheets and some basic chemical/chemical-engineering background) for the commercial-scale extraction of a number of minerals (NaCl , KCl , CaCl_2 , Na_2CO_3 , borax, Br_2 , I_2 , and Li) from brines. All of the processes described in Reference 20 incorporate a number of unit operations and some (such as for the production of KCl , Na_2CO_3 , and borax) are relatively complex. Reference 7 explores, in

some detail, the use of (and laboratory experiments with) sulfide precipitation of heavy metals (Pb, Zn, Ag, Mn, and Fe) from Imperial Valley geothermal brine.

Exhibits 5 and 6 identify (to the extent reported in the literature) the processes used, proposed, or discussed for minerals recovery from geothermal fluids and non-geothermal brines, respectively. As evident from these exhibits evaporation-crystallization is a very common method for minerals recovery. Multi-product recovery from a number of brine sources (e.g., Trona CA, Great Salt Lake UT, Midland MI, Searles Lake CA, and Sodom in Israel) involves fairly complex combinations of some of the processes identified earlier plus some others.

A tentative process flowsheet for an integrated geothermal minerals recovery operation is presented in Exhibits 7 and 8 (reproduced from Reference 20). This flowsheet was developed to cater for the characteristics of a fairly specific Imperial Valley type of brine (Sinclair No. 4/Magmamax No. 1); it should not be assumed to be applicable to all types of brines nor all geothermal energy applications. Details of the product-specific steps in Exhibit 7 can be found in Reference 20 in terms of existing brine technologies. It should be noted, however, that the extraction of chlorides involves brine evaporation, which will not usually be permitted due to the need to inject the spent brine from energy facilities.

Many industries, particularly the metal finishing and electroplating industries, have developed processes for the removal of poten-

EXHIBIT 5

PROCESSES REPORTED IN LITERATURE
AS USED OR APPLICABLE FOR
SITE-SPECIFIC MINERALS RECOVERY
FROM GEOTHERMAL FLUIDS

	SITES	PHYSICAL PROCESSES										CHEMICAL PROCESSES				
		Sedimentation	Flocculation/ Seeding	Evaporation/ Crystallization	Filtration	Distillation	Reverse Osmosis	Flotation	Air Stripping	Leaching	Other	Chemical Precipitation	Ion Exchange	Electrodialysis	Solvent Extraction	Other
CO ₂	<ul style="list-style-type: none"> • Kenya • Imperial Valley 															
H ₃ BO ₃	<ul style="list-style-type: none"> • Larderello • Tuscan Pools, ? • El Tatio, Chile 															
A ₃	<ul style="list-style-type: none"> • Wairakei 		X													
SiO ₂	<ul style="list-style-type: none"> • Wairakei • Broadlands 		X									X				
NaCl	<ul style="list-style-type: none"> • Reykjanes 															
	<ul style="list-style-type: none"> • Imperial Valley 			X												
	<ul style="list-style-type: none"> • Wairakei 												X			
KCl	<ul style="list-style-type: none"> • Cerro Prieto 			X												
	<ul style="list-style-type: none"> • Reykjanes 															
	<ul style="list-style-type: none"> • Imperial Valley 			X												
	<ul style="list-style-type: none"> • Wairakei 															
CaCl ₂	<ul style="list-style-type: none"> • Reykjanes 												X			
	<ul style="list-style-type: none"> • Imperial Valley 			X												

SOURCE: Compiled from references identified in Exhibit 3.

EXHIBIT 5

PROCESSES REPORTED IN LITERATURE
AS USED OR APPLICABLE FOR
SITE-SPECIFIC MINERALS RECOVERY
FROM GEOTHERMAL FLUIDS
(continued)

	SITES	PHYSICAL PROCESSES										CHEMICAL PROCESSES				
		Sedimentation	Flocculation/ Seeding	Evaporation/ Crystallization	Filtration	Distillation	Reverse Osmosis	Flotation	Air Stripping	Leaching	Other	Chemical Precipitation	Ion Exchange	Electrodialysis	Solvent Extraction	Other
LiCl	• Wairakei			X									X			
Pb, Zn, Ag, Fe, Mn	• Imperial Valley											X				
Li	• Imperial Valley • El Tatio, Chile															
Mg	• Ethiopia															
NH ₃	• Larderello															
H ₂ S	• Larderello															
S	• The Geysers															
(NH ₄) ₂ CO ₃	• Larderello															
NH ₄ Cl	• Larderello															
Sodium Perborate	• Larderello															
Manganese Borate	• Larderello															

PROCESSES REPORTED IN LITERATURE
AS USED OR APPLICABLE FOR
SITE-SPECIFIC MINERALS RECOVERY
FROM GEOTHERMAL FLUIDS
(concluded)

	SITES	PHYSICAL PROCESSES										CHEMICAL PROCESSES				
		Sedimentation	Flocculation/ Seeding	Evaporation/ Crystallization	Filtration	Distillation	Reverse Osmosis	Flotation	Air Stripping	Leaching	Other	Chemical Precipitation	Ion Exchange	Electrodialysis	Solvent Extraction	Other
Cs	<ul style="list-style-type: none"> • El Tatio, Chile • Wairakei 															
Rb	<ul style="list-style-type: none"> • El Tatio, Chile • Wairakei 															
Li ₂ CO ₃	<ul style="list-style-type: none"> • Wairakei 															
Borax	<ul style="list-style-type: none"> • Wairakei 															

PROCESSES REPORTED IN LITERATURE
AS USED OR APPLICABLE FOR
SITE-SPECIFIC MINERALS RECOVERY
FROM NON-GEOTHERMAL BRINES

	SITES	PHYSICAL PROCESSES										CHEMICAL PROCESSES				
		Sedimentation	Flocculation/ Seeding	Evaporation/ Crystallization	Filtration	Distillation	Reverse Osmosis	Flotation	Air Stripping	Leaching	Other	Chemical Precipitation	Ion Exchange	Electrodialysis	Solvent Extraction	Other
NaCl	• California			X												
	• Great Salt Lake, UT			X												
	• Wendover, UT			*				*								
	• Carlsbad, NM							X?								
	• Latin America, Australia, Asia, Africa			X												
	• Europe															
KCl	• Trona, CA			X												
	• Wendover, UT			*				*								
	• Great Salt Lake, UT			X												
	• Regina, Saskatchewan			X												
	• Sodom, Israel			*				*								
Na ₂ CO ₃	• Searles Lake, CA			*							X					
MgCl ₂	• U.S.A.															
	• Norway															
	• San Diego, CA			X												
	• Great Salt Lake, UT															
	• Midland, MI			*							*					
CaCl ₂	• Bristol Lake, CA			X												

* Indicates identified processes used in conjunction

SOURCE: Compiled from references identified in Exhibit 4.

EXHIBIT 3
PROCESSES REPORTED IN LITERATURE
AS USED OR APPLICABLE FOR
SITE-SPECIFIC MINERALS RECOVERY
FROM NON-GEOTHERMAL BRINES
(concluded)

	SITES	PHYSICAL PROCESSES										CHEMICAL PROCESSES				
		Sedimentation	Flocculation/ Seeding	Evaporation/ Crystallization	Filtration	Distillation	Reverse Osmosis	Flotation	Air Stripping	Leaching	Other	Chemical Precipitation	Ion Exchange	Electrodialysis	Solvent Extraction	Other
Borax	• Searles Lake, CA		*	*							*				*	
Br ₂	• U.S.										*					*
	• El Dorado, AR															
	• Israel			*				*			*					
	• ?										*				*	
I ₂	• U.S.										*					*
	• Woodward, OK															
Li	• Trona, CA										*					*
	• Silver Peak, NV			*											*	
	• Great Salt Lake, UT			X												
	• Clayton Valley, NV															
	• Searles Lake, CA															
	• Smackover Formation, TX/AR															
Mg	• Ogden, UT															
	• Ludington, MI															
	• Freeport, TX															
	• Port St. Joe, FL															

* Indicates identified processes used in conjunction.

EXHIBIT 7

POSSIBLE FLOWSHEET FOR GEOTHERMAL
BRINE PROCESSING TO RECOVER MINERALS

SOURCE: Reference 20.

EXHIBIT 8
PRODUCTION OF PURE KCL FROM GEOTHERMAL BRINE

SOURCE: Reference 20.

tially-toxic heavy metal ions from their waste streams to comply with environmental regulations. Many of these processes could be directly applicable for the treatment of spent geothermal fluids.

The solubilities of metal ions are very dependent upon the pH of the solution (see Exhibit 9). By increasing the pH, metal ions will precipitate out as metal hydroxide. Thus, metal ions are removed by the addition of an alkali, such as lime or caustic soda, to adjust the pH of the wastewater to the point where the metals exhibit minimum solubilities for different metals occur at different pH values. For a mixture of metal ions, it is not possible to achieve minimum solubilities for all metal ions. Therefore, a compromise pH value that produces significant low, though not minimum, solubilities for the metal ions must be used. Another disadvantage of hydroxide precipitation is that metal hydroxide precipitates tend to redissolve if the solution pH is increased or decreased from their minimum solubility.

The situation in geothermal applications may become more complex, especially when chemical additives are used in the control of scale formation. Most of these chemicals are chelating agents and will affect the solubility of metal ions, consequently affecting metal removal efficiencies.

There are alternatives to the hydroxide precipitation process to improve metal ion removal efficiency. Sulfide precipitation is very effective for removing heavy metals from industrial waste streams because of the extremely low solubility of metal sulfides over a broad pH range (see Exhibit 10). Sulfide precipitation can also achieve low metal solubility in the presence of many complexing and chelating agents.

EXHIBIT 9
METAL SOLUBILITY AS A FUNCTION OF pH

SOURCE: Reference 22.

EXHIBIT 10
SOLUBILITIES OF METAL HYDROXIDES AND
SULFIDES AS A FUNCTION OF pH

SOURCE: Reference 22.

Highly-simplified process flow diagrams for hydroxide and sulfide treatment systems are shown in Exhibit 11. These systems produce hydroxide or sulfide sludge that must be disposed of. The results of a two-year laboratory investigation into the sulfide recovery of heavy metals from Imperial Valley geothermal brines are described in Reference 7 and mentioned elsewhere in this report. Recounted elsewhere in this report, too, is laboratory and pilot-plant experience with metal hydroxide precipitation from Imperial Valley geothermal brine.

As a spent brine utilization operation, by-product recovery must be technologically compatible with the geothermal energy facility in terms of energy production requirements, environmental constraints, and other considerations. Some of the factors which may be involved are identified below.

- Injection of spent brine in order to prevent subsidence and/or to recharge the geothermal reservoir.
- Particulates removal from spent brine to facilitate injection.
- Brine treatment for environmental purposes (primarily for surface brine disposal).
- Corrosiveness and solids deposition of geothermal brines.
- Recovery systems upstream of the turbine in electric applications and upstream of the heat exchanger in direct-heat applications will probably not be practical due to attendant thermal losses which would lower energy use efficiency.
- Miscellaneous operational characteristics of the energy facility, e.g., frequent or prolonged shutdowns, fluctuating flow rates, variable brine characteristics, brine temperature changes, addition of chemicals to brine for scaling and corrosion control, etc.
- Disposal of residual liquid/solid wastes from by-product recovery.
- Appropriateness of climatic conditions for solar evaporation, where used.

EXHIBIT 11
WASTEWATER TREATMENT PROCESSES FOR REMOVING HEAVY METALS

SOURCE: Reference 22

Similar considerations apply to any recovery contemplated from waste sludges produced from the energy system.

- (7) What quantities and qualities of materials could be produced and are they marketable?

Initial consideration of recoverable amounts of by-products from geothermal fluids must, obviously, be based on the maximum amount available in the source. Fluids of high salinity, such as those in the Salton Sea area, would potentially yield more recoverable products than low salinity fluids. Exhibit 12 identifies the quantities of constituents theoretically recoverable from a "typical" 50 MWe geothermal power plant* utilizing high-salinity brine. For most chemical species, the concentrations listed in Exhibit 12 represent the upper limit of the materials detected in the Salton Sea resource (see Exhibit 2), which is one of most saline geothermal resources in the U.S. No quantitative values for Cd, Cr, Co, Mo, Se, and I are given in Exhibit 2 for the Salton Sea resource, so numerical values for these components have been taken from other sources (20).

The types and the amounts of materials most readily recoverable from geothermal fluids are also listed in Exhibit 12 ("Major Compounds" column). The amounts of recoverable materials range from a low of one ton of Hg compound per year to over 900,000 tons of salt per year. Since the concentrations of chemical species used in this exhibit are based on the upper limits of reported ranges, the

* These calculations assume the following characteristics of a 50 MWe geothermal power plant:

- Brine flow rate = 100,000 lb/hr per well
- Fourteen production wells are required
- Plant operates 7,000 hr/year (0.8 capacity factor)

**EXHIBIT 12. ANNUAL AMOUNTS OF RECOVERABLE MATERIALS
IN A BEST CASE 50 MWe PLANT**

1 of 2

SPECIES	CONCENTRATION (ppm)	MAJOR COMPOUNDS	AMOUNT OF RECOVERABLE MATERIALS	
			Cations/Anions (tons)	Chemicals (tons)
Cl ⁻				
Na ⁺	74,000	NaCl NaOH Na ₂ CO ₃	363,000 363,000 363,000	919,000 630,000 835,000
Ca ⁺²	40,000	CaCl ₂ CaCO ₃ CaSO ₄	196,000 196,000 196,000	544,000 490,000 666,000
K ⁺	25,000	KCl	122,000 122,000	233,000 175,000
Mg ⁺²	3,000	MgO Mg	14,700 14,700	24,400 14,700
Fe ⁺³	3,000	Fe(OH) ₃ (ORE) Fe ₂ S ₃	14,700 14,700	28,100 27,300
Si ⁺⁴	1,000	CaOSiO ₂	4,900 4,900	20,200 4,900
CO ₂	1,000	CO ₂	4,900	4,900
Sr ⁺²	750	SrSO ₄ SrCO ₃ Sr	3,650 3,650 3,650	7,730 6,210 3,650
B ⁻³	740	Na ₂ B ₄ O ₇ ·H ₂ O	3,650	32,000
Zn ⁺²	740	Zn(OH) ₂ ZnSO ₄ Zn	3,625 3,625 3,625	5,510 8,980 3,625
Ba ⁺²	570	BaSO ₄ (ORE) BaSO ₄ (PURE) BaCl ₂	2,790 2,790 2,790	---- 4,750 4,240
Al ⁺³	450	Al ₂ O ₃ Al ₂ (SO ₄) ₃ AlCl ₃ Al	2,200 2,200 2,200 2,200	4,170 13,900 10,900 2,200
Li ⁺	300	Li ₂ O·Al ₂ O ₃ ·4SiO ₂ Li ₂ CO ₃ LiOH·H ₂ O LiAlO ₂	1,470 1,470 1,470 1,470	---- 7,770 8,820 13,860
NH ₃	300	NH ₃	1,470	1,470
Rb ⁺¹	169	Rb (ORE) RbCl Rb	828 828 828	---- 1,170 828
Pb ⁺²	155	Pb (ORE) PbO Pb	760 760 760	---- 820 875
Br ⁻	146	NaBr Br ₂	715 715	920 715
Mo	110	MoO (ORE) MoO Mo	540 540 540	---- 730 540
SO ₄ ⁼	56	Na ₂ SO ₄	274	405
I ⁻	40	NaI I ₂	196 196	231 196

EXHIBIT 12. ANNUAL AMOUNTS OF RECOVERABLE MATERIALS
IN A BEST CASE 50 MWe PLANT (CONCLUDED)

2 of 2

SPECIES	CONCENTRATION * (ppm)	MAJOR COMPOUNDS	AMOUNT OF RECOVERABLE MATERIALS	
			Cations/Anions (tons)	Chemicals (tons)
H ₂ S	30	S	147	138
Cs ⁺	20	CsCO (ORE)	98	----
		CsCl	98	124
		Cs	98	98
Cr ⁺³	19	Cr (ORE)	93	----
		Cr(OH) ₃	93	184
		Cr	93	93
F ⁻	18	CaF ₂	88	273
Cu ⁺²	16	CuO (ORE)	78	----
		Cu(OH) ₂	78	120
		CuS	78	98
		Cu	78	78
As ⁺³	15	As ₂ O ₃	73	----
		As ₂ O ₃	73	96
		As	73	73
Se ⁻²	8.2	Na ₂ Se	40	63
		Se ²⁻	40	40
Ni ⁺²	6.5	Ni (ORE)	32	----
		Ni(OH) ₂	32	51
		NiS	32	50
		Ni	32	32
Mn ⁺²	6	Mn (ORE)	29	----
		Mn(OH) ₂	29	47
		Mn	29	29
Cd ⁺²	2.4	CdO (ORE)	12	----
		Cd(OH) ₂	12	15
		Cd	12	12
Au	2	Au	9.8	9.8
Ag ⁺	1.4	Ag	7	7
Hg ⁺²	0.2	Hg (ORE)	1	----
		Hg(OH) ₂	1	1.2
		HgS	1	1.2
		Hg	1	1
Co ⁺²	0.2	Co (ORE)	1	----
		Co(OH) ₂	1	1.5
		CoS	1	1.5
		Co	1	1

* Concentrations are upper limit levels for Salton Sea brines given in Exhibit 2, except for Cd, Cr, Co, Mo, Se, and I which are taken from Reference 20 and Au from Reference 1.

amounts of recoverable materials calculated represent a "best-case" scenario. For fluids where the salinity is lower than that of the Salton Sea, the amounts of recoverable products will obviously be less.

In order to consider the market potentials of these chemicals/minerals, it is necessary to first establish the values of the materials. Market values for chemicals are very much dependent upon their grades and qualities. Most inorganic chemicals are produced from minerals containing ores and, generally, several processes are required to convert these ores to marketable products. Ore-grade substances are generally least expensive, becoming more expensive as they are refined and reprocessed into pure metals or other chemicals. For example, Rb as an ore costs about \$200/ton, but when converted into Rb metal, it costs \$600,000/ton.

Exhibit 13 lists the potential monetary values obtainable if all the identified minerals could be completely recovered from geothermal fluids and sold at current market prices. Looking at the most likely recoverable form of each listed brine species, 14 products exceed \$1,000,000/year in value:

• RbCl	• MgO
• Au	• ZnSO ₄
• Li ₂ CO ₃	• NaCl
• CsCl	• SrCO ₃
• KCl	• CaSO ₄
• Na ₂ B ₄ O ₇ H ₂ O	• I ₂
• MoO	• Ag

**EXHIBIT 13. ANNUAL MINERAL VALUES IN A
BEST CASE 50 MWe PLANT**

1 of 2

SPECIES	CONCENTRATION (ppm)	MAJOR COMPOUNDS	MINERAL VALUES	
			Dollars per ton	Values in One 50 MWe Plant
Cl ⁻				
Na ⁺	74,000	NaCl NaOH Na ₂ CO ₃	\$4.50	\$4,135,000
Ca ⁺²	40,000	CaCl ₂ CaCO ₃ CaSO ₄	\$2.88 \$7.00	\$1,411,000 \$3,430,000
K ⁺	25,000	KCl KOH	\$87.00	\$10,600,000
Mg ⁺²	3,000	MgO Mg	\$200.00 \$2,000.00	\$4,950,000 \$49,500,000
Fe ⁺³	3,000	Fe(OH) ₃ (ORE) Fe ₂ S ₃	\$54.00	\$794,000
Si ⁺⁴	1,000	CaOSiO ₂ Si	\$42.00 (Si) \$1,200.00	\$206,000 \$9,800,000
CO ₂	1,000	CO ₂	\$62.00	\$304,000
Sr	750	SrSO ₄ (ORE) SrCO ₃ Sr	\$54.00 \$580.00	\$417,000 \$3,600,000
B ⁻³	740	Na ₂ B ₄ O ₇ ·H ₂ O	\$167.00	\$5,340,000
Zn ⁺²	740	Zn(OH) ₂ ZnSO ₄ Zn	\$900.00 \$540.00 \$760.00	\$4,960,000 \$4,850,000 \$2,540,000
Ba ⁺²	570	BaSO ₄ (ORE) BaSO ₄ (PURE) BaCl ₂	\$25.00 \$55.50 \$300.00	\$119,000 \$264,000 \$1,270,000
Al	450	Al ₂ O ₃ Al ₂ (SO ₄) ₃ AlCl ₃ Al	\$190.00 \$160.00 \$1,000.00 \$1,200.00	\$792,000 \$2,225,000 \$10,900,000 \$2,640,000
Li	300	Li ₂ O·Al ₂ O ₃ ·4SiO ₂ Li ₂ CO ₃ LiOH·H ₂ O	\$4,600.00 Li \$2,600.00 \$3,400.00	\$6,760,000 \$20,200,000 \$30,000,000
NH ₃	300	NH ₃	\$120.00	\$176,000
Rb ⁺	169	Rb (ORE) RbCl Rb	\$200.00 \$110,000.00 \$600,000.00	\$166,000 \$129,000,000 \$497,000,000
Pb	155	Pb (ORE) PbO Pb	 \$860.00	 \$654,000
Br ⁻	146	NaBr Br ₂	 \$440.00	 \$315,000
Mo	110	MoO (ORE) MoO Mo	 \$7,000.00 \$12,000.00	 \$5,110,000 \$6,480,000
SO ₄ ⁼	56	Na ₂ SO ₄		
I ⁻	40	NaI I ₂	 \$13,600.00	 \$2,665,000

EXHIBIT 13. ANNUAL MINERAL VALUES IN A
BEST CASE 50 MWe PLANT (CONCLUDED)

2 of 2

SPECIES	CONCENTRATION * (ppm)	MAJOR COMPOUNDS	MINERAL VALUES	
			Dollars per ton	Values in One 30 MWe Plant
H ₂ S	30	S	56.00	\$7,730
Cs ⁺	20	CsO (ORE) CsCl Cs	\$2,000.00 \$132,000.00 \$600,000.00	\$196,000 \$16,400,000 \$58,800,000
Cr ⁺³	19	Cr (ORE) Cr(OH) ₃ Cr	\$135.00	\$12,600
F ⁻	18	CaF ₂	\$100.00	\$27,300
Cu ⁺²	16	CuO (ORE) Cu(OH) ₂ CuS Cu	\$2,200.00	\$172,000
As	15	As ₂ O ₃ (ORE) As ₂ O ₃ As	\$700.00	\$67,000
Se ⁻²	8.2	Na ₂ Se Se	\$2,200.00	\$880,000
Ni ⁺²	6.5	Ni (ORE) Ni(OH) ₂ NiS Ni	\$5,000.00	\$160,000
Mn ⁺²	6	Mn (ORE) Mn(OH) ₂ Mn	\$1.50	\$43
Cd ⁺²	2.4	CdO (ORE) Cd(OH) ₂ Cd	\$6,000.00	\$72,000
Au	2	Au	\$8,400,000.00	\$82,300,000
Ag	1.4	Ag	\$168,000.00	\$1,176,000
Hg	0.2	Hg (ORE) Hg(OH) ₂ HgS Hg	\$1.00 \$10,500.00	 \$10,500
Co	0.2	Co (ORE) Co(OH) ₂ CoS Co	\$1.00 \$50,000.00	 \$50,000

* Concentrations are upper limit levels for Salton Sea brines given in Exhibit 2, except for Cd, Cr, Co, Mo, Se, and I which are taken from Reference 20 and Au from Reference 1.

Similarly, 10 products have values falling between \$100,000/year and \$1,000,000/year:

• $\text{Fe}(\text{OH})_3$	• BaSO_4
• Al_2O_3	• CaSiO_3
• Pb	• NH_3
• Br_2	• Cu
• CO_2	• Ni

In order to more fully assess the market potential of geothermal by-products, it is necessary to consider the current demands for these chemical species. (Appendix B includes the current annual U.S. demand for the minerals/chemicals under consideration in this study as well as the extent to which demand is met by imports.) Comparing the amounts of by-products obtainable with the U.S. demand provides some insight into the marketability of geothermal by-products. Exhibit 14 lists, in decreasing order, the monetary mineral values contained in the fluid of a "best-case" 50 MWe geothermal plant, along with other pertinent facts. Exhibit 15 illustrates the demand and strategic considerations from Exhibit 14 and also identifies, where applicable, countries supplying the commodities to the U.S.

The foregoing information, along with other considerations identified in Appendix C, has been collectively used for a preliminary assessment of the marketability of geothermal by-products. As a result of this assessment (described in greater detail in Appendix C), the minerals have been classified into 4 groups:

- Promising
- Marginally promising

EXHIBIT 14. FACTORS CONSIDERED IN DETERMINING THE
MARKETABILITY OF GEOTHERMAL BY-PRODUCTS

SPECIFICS	CONCENTRATION	MINERAL VALUE	% OF U.S. DEMAND FROM 50 MWe PLANT	% OF U.S. DEMAND MET BY IMPORT	STRATEGIC CONSIDERATIONS	CURRENT SUPPLY SOURCES
Rb	169	\$129,000,000	72,000	0	-	Ore
Au	2	\$83,000,000	5	45	Stockpiled	Ore
Li	300	\$20,000,000	46	0	-	Brines/Ore
Cs	20	\$16,400,000	700	100	-	Ore
K	25,000	\$10,600,000	3.3	68	-	Seawater/Brine
B	740	\$5,340,000	2.9	0	-	Brine
Mo	110	\$5,110,000	1.5	0	Strategic	Ore
Mg	300	\$4,950,000	1.3	0	-	Ore/Seawater
Zn	740	\$4,850,000	0.36	51	-	Ore
Na	74,000	\$4,135,000	1.8	9.5	-	Seawater
Sr	750	\$3,600,000	16.7	100	-	Ore
Ca	40,000	\$3,430,000	1.2	2	-	Limestone
I ₂	40	\$2,665,000	4.5	72	Stockpiled	Brine
Ag	1.4	\$1,175,000	0.11	30	-	Ore
Fe	3,000	\$793,000	0.008	33	-	Ore
Al	450	\$792,000	0.003	93	Controlled	Ore
Pb	155	\$654,000	0.05	15	Strategic Stockpiled Control	Ore
Br ₂	146	\$315,000	0.38	0	-	Brine
CO ₂	1,000	\$304,000	0.013	0	-	Natural Wells By-Products of Gasification
Ba	570	\$264,000	0.16	33	-	Ore
Si	1,000	\$206,000	0.7	13	Stockpiled	Ore
NH ₃	300	\$176,000	0.008	5	-	Natural Gas
Cu	16	\$172,000	0.003	13	Strategic Stockpiled	Ore
Ni	6	\$160,000	0.015	65	Stockpiled	Ore

EXHIBIT 15

IMPORT AND STRATEGIC CONSIDERATIONS FOR SELECTED MATERIALS

* Strategic Considerations

C = Controlled Material (by U.S. Government)

S = Strategic Material

SP = Stockpiled Material

- Speculative
 - o Not promising.

Exhibit 16 summarizes this assessment and briefly highlights the advantages and disadvantages of each recovery system.

Exhibit 17 summarizes the salient characteristics of some recovery operations using geothermal fluids. Not all of the processes described are commercialized and not all of them have been specifically intended for by-product recovery (especially the H₂S abatement systems which produce sulfur-bearing wastes).

Of particular interest are the results of a 2-year laboratory investigation of sulfide precipitation of heavy metals from high-salinity geothermal brine (7). The recovery of Pb, Zn, and Ag as sulfides has been demonstrated. However, mixtures of sulfides of these elements with those of Fe and Mn (which are considered undesirable products) appear unavoidable in most situations. In addition, about 20 other elements were found in minor amounts in the recovered solids. The percentage recoveries of the metals and the chemical composition of the produced solids vary, depending on factors such as pH, temperature, residence time, nature and concentration of sulfiding agent, and even reactor-vessel size. The results of this series of laboratory experiments cannot be automatically extrapolated to commercial technology: pilot-plant testing would be needed to realistically assess scaled-up operations.

Exhibits 18 and 19 present information on the constituent removal efficiencies of various conventional wastewater treatment techniques. These figures are intended only as a relative guide to the possible

EXHIBIT 16. RECOVERY POTENTIAL OF
GEOTHERMAL MINERALS

MINERAL	RATIONALE
<u>PROMISING</u>	
<ul style="list-style-type: none"> • Lithium (Li) • Boron (B) • Carbon Dioxide (CO₂) • Ammonia (NH₃) • Iodine (I₂) • Strontium (Sr) • Heavy Metals (Ni, Cd, Pb, Fe, Mo, Zn) 	<ul style="list-style-type: none"> • High Mineral Value (\$20,000,000/year) • Recovery by LiAlO₂ looks promising • Recovery of borax from brine is a demonstrated technology • Relatively easily recovered • May be able to penetrate small local markets • Can be used on-site • Relatively easily recovered • Recovery of I₂ from brine is demonstrated, but with high resource uncertainty. • High mineral value • High import dependency • Can be collectively precipitated as hydroxides or sulfides
<u>MARGINALLY-PROMISING</u>	
<ul style="list-style-type: none"> • Magnesium (Mg) • Aluminum (Al) • Barium (Ba) 	<ul style="list-style-type: none"> • Stiff competition from seawater • Low mineral value but high import dependence • Low mineral value but can be used on-site as a weighting material for drilling mud
<u>SPECULATING</u>	
<ul style="list-style-type: none"> • Gold (Au) • Silver (Ag) 	<ul style="list-style-type: none"> • Uncertainty of gold content in geothermal fluids • Resource Uncertainty
<u>NOT-PROMISING</u>	
<ul style="list-style-type: none"> • Rubidium (Rb) • Cesium (Ce) • Sodium (Na) • Potassium (K) • Calcium (Ca) • Silicon (Si) 	<ul style="list-style-type: none"> • Low market demand • Low market demand • Can only be economically recovered by solar evaporation • Competition from seawater and other brines • Can only be economically recovered by solar evaporation • May be deposited as scales in the energy conversion system • Ample supply of limestone (CaCO₃) • Value of silicate very much dependent upon its purity

REPORTED ESTIMATES OF RECOVERY
EFFICIENCY AND PRODUCT PURITY FOR
GEOTHERMAL BY-PRODUCT RECOVERY

PRODUCT	RECOVERY EFFICIENCY (%)	RECOVERY TECHNIQUE	SPECIAL CONDITIONS	PRODUCT PURITY	COMMENTS	REFERENCE (DATE)*
Lead	95	Sulfide precipitation followed by pressure filtering	Continuous; 80-90°C; Na ₂ S	-	<ul style="list-style-type: none"> Results of 2-year lab study using Salton Sea brines. A computer program was developed to study/predict process characteristics Batch and continuous processes tested Three sulfiding agents tested: H₂S, Na₂S, NaHS Different reactor vessel sizes tested Fe and Mn considered unwanted products 	7 (1980)
	?		To achieve 85% Zn recovery	31% ZnS, 5% PbS, 9% FeS, 14% MnS, ~41% SiO ₂ ; ~20 other elements included		
Zinc	> 90		Batch; Na ₂ S	ZnS, FeS, MnS		
	85		-	31% ZnS, 5% PbS, 9% FeS, 14% MnS, ~41% SiO ₂ ; ~20 other elements included		
Iron	40-45		-	Unwanted component of Pb and Zn recovered products (as above)		
Manganese	20		-	Unwanted component of Pb and Zn recovered products (as above)		
Silver	100					
Arsenic	90-98 expected	Coprecipitation with iron to form an iron floc	Addition of acid ferrous sulfate and oxidize it at pH 3.5-5	Arsenic-iron floc	<ul style="list-style-type: none"> Floc enhancement and arsenic recovery needed, which will produce 90-98% removal in floc Wairakei brine 	5 (1981)
Silica	~100	Precipitation as calcium silicate followed by settlement and pressure filtration	<ul style="list-style-type: none"> Excess CaO 	<ul style="list-style-type: none"> SiO₂, CaO, As, B 50% water 	<ul style="list-style-type: none"> CaO addition Wairakei and Broadlands brines 	5 (1981)
	13	Silica seeding in fluidized bed followed by removal in continuous flow ball mills			<ul style="list-style-type: none"> Wairakei brine 	

*The publication dates of the referenced reports are included for guidance, but it must be remembered that the activity described or information noted may date from much earlier than implied by the publication date.

REPORTED ESTIMATES OF RECOVERY
EFFICIENCY AND PRODUCT PURITY FOR
GEOTHERMAL BY-PRODUCT RECOVERY
(continued)

PRODUCT	RECOVERY EFFICIENCY (%)	RECOVERY TECHNIQUES	SPECIAL CONDITIONS	PRODUCT PURITY	COMMENTS	REFERENC (DATE)*
Boron		Precipitation of borax	If sufficient Na^+ is present	Borax (contains B and Na)		5 (1981)
		Distillation of $(\text{CH}_3)_3\text{BO}_3$	<ul style="list-style-type: none"> • Add CH_3OH and H_2SO_4 • Recover borate as borax 	Borax (contains B and Na)	<ul style="list-style-type: none"> • Method considered for power plant at Ahuachapan, El Salvador 	
	70	Use of Ca and Mg oxides, hydroxides, and carbonates	<ul style="list-style-type: none"> • Produce $\text{Mg}(\text{OH})_2$ from $\text{Ca}(\text{OH})_2 + \text{MgCO}_3$ • B sorbs on $\text{Mg}(\text{OH})_2$ 		<ul style="list-style-type: none"> • Costly method due to tremendous dosages needed 	
	40				<ul style="list-style-type: none"> • Turkish study of CaO treatment to remove SiO_2 found B also removed 	
	70-80		<ul style="list-style-type: none"> • Use MgO 			
		Co-precipitation of B with hydroxides of Ni, Cr, Zn, Ti, Mn, Sn, Mg, and Al			<ul style="list-style-type: none"> • Russian study 	
Potassium Chloride		High NaCl-KCl content salts from evaporation ponds separated by flotation			<ul style="list-style-type: none"> • Study conducted at Cerro Prieto, Mexico • Might be extended to recovery of Na_2CO_3 and chlorine 	5 (1981)
Sulfur	80-90	Stretford process for H_2S emission abatement	Scrubs non-condensable gases from condenser ejector (surface-contact condenser)	Commercially pure (99%)	<ul style="list-style-type: none"> • 10-20% of H_2S remains in condensate and emitted from, or further controlled in, cooling towers. • In use at The Geysers 	15 (1978)
	90-92	Iron Catalyst process for H_2S emission abatement	Cooling water treatment upstream of cooling tower (direct-contact condenser)	Elemental S in a toxic sludge	<ul style="list-style-type: none"> • In use at The Geysers 	

REPORTED ESTIMATES OF RECOVERY
EFFICIENCY AND PRODUCT PURITY FOR
GEOTHERMAL BY-PRODUCT RECOVERY
(Concluded)

PRODUCT	RECOVERY EFFICIENCY (%)	RECOVERY TECHNIQUE	SPECIAL CONDITIONS	PRODUCT PURITY	COMMENTS	REFERENCE (DATE)*
Sulfur (Cont'd)	>97	EIC Process for H ₂ S emission abatement	Treatment of raw geothermal steam	Copper sulfide slurry	<ul style="list-style-type: none"> Field tested at The Geysers Capital costs extremely high Also removes NH₃ & B 	15 (1978)
	~100	Dow Oxygenation Process for H ₂ S emission abate- ment	Removes H ₂ S from wellhead brine (liquid)	Generally 80% SO ₄ ²⁻ 10% S, and 10% SO ₃ ²⁻	<ul style="list-style-type: none"> Technical feasibility demonstrated in lab experiment 	
		Various other techniques/ concepts for H ₂ S abatement			<ul style="list-style-type: none"> Mostly in very early evaluation stages 	
Dissolved Solids		Reactor-Clarifier	Solids precipitated by seeding and solids separated, filtered, and pressed into cake	?	<ul style="list-style-type: none"> System under development at GLEF at Salton Sea 	12 (1980)

PROCESS EFFICIENCY (%)						
	Sedimentation	Chemical Precipitation	Filtration	Electro- dialysis	Ion Exchange	Reverse Osmosis
TS	20-40	40-60	70-95	30-50	80-90	90-99
TDS	10	20-40	10	30-40	80-90	85-95
Fe	10-30	60-100	70-95	30-40	80-90	95-98
Mn	10-30	65.4-99.4	90-98	30-40	80-90	95-98
B	10	20-40	20-40	10	80-90	60-80
Zn	10-30	90-95	60-85	30-40	80-90	85-95
Ba	10	85-99	80-98	99.9	99	95-98
F	10	99	10	10	80-90	88-92
Pb	10-30	95-97	95-98	30-40	80-90	95-98
Cu	10-30	80-85	90-95	30-40	80-90	95-98
As	10-30	80-98	75-95	30-40	80-90	85-95
Hg	10-30	40-60	70-80	30-40	80-90	85-95
Se	10-30	80-90	90-95	30-40	99.7	85-95
Cr	10-30	60-99	60-99	30-40	80-90	85-95
Ag	10-30	90-99	90-99	30-40	85-95	85-95
Cd	10-30	85-95	90-98	30-40	80-90	85-95

EXHIBIT 18

REPORTED EFFICIENCIES OF WASTEWATER
TREATMENT TECHNOLOGIES FOR SPECIFIC CONSTITUENTS

SOURCE: Reference 15.

	Efficiency (%)	
	Total Solids	Soluble Metals
Sedimentation	30	5
Chemical Precipitation	50	80
Filtration	85	85
Electrodialysis	40	35
Ion Exchange	85	90
Reverse Osmosis	90	90
Evaporation	99.9	95

EXHIBIT 19

ASSIGNED EFFICIENCIES OF VARIOUS TREATMENT
SYSTEMS FOR REMOVING CROSS CONSTITUENTS

SOURCE: Reference 15.

application of these techniques to geothermal brine treatment. The figures are not the results of any direct experimentation with geothermal brines.

(8) What costs are involved with these technologies?

Because of the lack of operating experience of by-product recovery from geothermal energy resources, it makes the cost estimate of such operations difficult. In addition, no cost data are contained in the readily-accessible open literature for commercial or pilot plant systems which have utilized geothermal fluids. Other industries, such as the metal and electroplating industry, and the photographic processing industry, generally incorporates byproducts recovery, or wastewater recycling and reuse, in the production process. These cost figures would be a more appropriate baseline for estimating geothermal byproduct recovery costs, particularly for cost associated with the recovery of heavy metals. Unfortunately, costs associated with these processes are generally proprietary in nature and are not readily available.

Since the extraction of certain constituents from geothermal fluid is tantamount to wastewater treatment, it is appropriate to examine the costs of conventional wastewater treatment technologies. Preliminary capital and operational cost estimates for potentially applicable treatment technologies are identified in Exhibit 20. It is important to note, however, that these costs do not include sludge processing. In fact, sludge produced from these processes contain approximately 95 percent water and extensive processing will be required before marketable products can be produced.

Process	\$/1000 liters @ 10 lpm	\$/1000 liters @ 100,000 lpm
Sedimentation	2.50	.01
1-stage lime addition	4.50	.02
2-stage lime addition	6.00	.01
Alum addition	4.50	.06
Ferric chloride addition	6.00	.07
Filtration	1.10	.06
Ion exchange	.30	.09
Reverse Osmosis	.30	.12
Electrodialysis		.30
Vapor compression evaporation	.60	.20
Multieffect evaporation	.90	.50
Multistage evaporation	.90	.50

EXHIBIT 20
SUMMARY OF ESTIMATED WASTEWATER
TREATMENT COSTS

(9) How might by-products recovery operations affect the overall economics of geothermal energy development?

The feasibility of by-product recovery and its impact on geothermal energy development will be project-specific issues. Important parameters which will influence the economic implications of recovery are:

- Product quantity
- Product quality
- Product value/derived income
- Recovery cost
- Market availability/access
- "Selling" cost
- Secondary-waste treatment and disposal requirements, if any.

The ability to estimate the income that could be realized from by-product recovery and sale is very limited at this stage. Several preliminary estimates have been made under particular scenarios, but their accuracy must be viewed critically. Major results of these studies, as available, are given in Exhibit 21. It should be borne in mind that the potential value of geothermal by-product recovery, in many cases, has been expressed in terms of product value. This figure does not take into account the costs of recovery or marketing of the product. Given the status of experience and state of knowledge concerning geobrine minerals recovery, it is advisable to view the economic features of the operations described in Exhibit 21 fairly critically.

A number of commercial and pilot-plant systems for minerals recovery from geothermal fluids around the world have been identified

EXHIBIT 21

REPORTED ESTIMATES OF ECONOMIC CHARACTERISTICS OF
BY-PRODUCT RECOVERY FROM GEOTHERMAL FLUIDS

SITE	RECOVERED/ RECOVERABLE PRODUCTS	ECONOMIC CHARACTERISTICS OF POSSIBLE RECOVERY	ASSUMPTIONS	REFER- ENCES (DATE)*
lton Sea, alifornia	9 metals, including Au	<ul style="list-style-type: none"> • Annual return of \$265,000 per well per yr. 	<ul style="list-style-type: none"> • "Conservative" estimates of mineral concentrations • Output of 150 tons per hr. per well • Well operates 7000 hr./yr. 	1 (1978)
Tatio, hile	Li, Cs, Rb	<ul style="list-style-type: none"> • Investment of \$8.8 million • Annual sales of \$9 million • Cash flow payoff of 1.7 yrs • Profit before taxes of 66% • Break-even point for sales of 22.4% of production capacity 	<ul style="list-style-type: none"> • 10-well system 	1 (1978)
irakei, ew Zealand	As	<ul style="list-style-type: none"> • As value of \$260,000/yr. • Does not compensate for expenditures 	<ul style="list-style-type: none"> • 4.8 ppm As • Market price of \$1000/tonne • Flow rate of 5,000 tonnes water per hr. 	5 (1981)
oadlands, ew Zealand	CaSiO ₃	<ul style="list-style-type: none"> • 80,000 tonnes/yr. valued at \$8 - \$80 million/yr. 	<ul style="list-style-type: none"> • Market value of CaSiO₃ between \$100 and \$1,000/tonne • 80 MWe power station • From discharge with 700 ppm SiO₂ 	5 (1981)
irakei, ew Zealand	B ₂ O ₃	<ul style="list-style-type: none"> • 1981 product value of \$600,000 	<ul style="list-style-type: none"> • 117 ppm HBO₂ • 100 MWe power plant • 5,000 tonnes/hr. water flow • Product value of \$150/tonne 	5 (1981)

EXHIBIT 21

REPORTED ESTIMATES OF ECONOMIC CHARACTERISTICS OF

BY-PRODUCT RECOVERY FROM GEOTHERMAL FLUIDS

(continued)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	ECONOMIC CHARACTERISTICS OF POSSIBLE RECOVERY	ASSUMPTIONS	REFER- ENCES
Ngawha, New Zealand	B ₂ O ₃	<ul style="list-style-type: none"> 1981 product value of \$7.5 million 	<ul style="list-style-type: none"> 3,690 ppm HBO₂ 100 MWe power plant 2,000 tonnes/hr. water flow Product value of \$150/tonne 	5 (1981)
Salton Sea, California		<ul style="list-style-type: none"> 1981 product value of \$4.2 million 	<ul style="list-style-type: none"> 210 ppm HBO₂ 100 MWe power plant 2,000 tonnes/hr. water flow Product value of \$150/tonne 	
Terro Prieto, Mexico	KCl	<ul style="list-style-type: none"> 200,000 tonnes/yr. KCl valued at \$14 million 	<ul style="list-style-type: none"> 400 MWe power plant 	5 (1981)
Geysers, California	S	<ul style="list-style-type: none"> 3,000 tonnes/yr. S for 110 MWe power plant valued at \$43,000/yr. 	<ul style="list-style-type: none"> Recovery through H₂S abatement 3.7 kg/hr/MWe H₂S emission 1981 value of \$140/tonne 	5 (1981)
Salton Sea, California		<ul style="list-style-type: none"> 150 tonnes/yr. S for 110 MWe power plant valued at \$21,000/yr. 	<ul style="list-style-type: none"> Recovery through H₂S abatement 0.16 kg/hr/MWe H₂S emission 1981 value of \$140/tonne 	
Roadlands, New Zealand		<ul style="list-style-type: none"> 4,700 tonnes/yr. S for 110 MWe power plant valued at \$650,000/yr. 	<ul style="list-style-type: none"> Recovery through H₂S abatement Up to 5/kg/hr/MWe H₂S emission 1981 value of \$140/tonne 	
Salton Sea, California	Heavy Metals	<ul style="list-style-type: none"> Gross metal value of \$670,000/yr. for a 55 MWe power plant Metal value of \$15.8-\$105 million/yr. for Salton Sea 	<ul style="list-style-type: none"> 1,300 - 8,700 MWe of capacity in Salton Sea Heavy metal value of Niland brine about \$1.30/1,000 gallons 	7 (1980)

EXHIBIT 21

REPORTED ESTIMATES OF ECONOMIC CHARACTERISTICS OF
BY-PRODUCT RECOVERY FROM GEOTHERMAL FLUIDS

(concluded)

SITE	RECOVERED/ RECOVERABLE PRODUCTS	ECONOMIC CHARACTERISTICS OF POSSIBLE RECOVERY		ASSUMPTIONS	REFER- ENCES (DATE)*
nclair No. 4 ine, perial lley		<u>Quantity</u> (tons/day)	<u>Income</u> (10 ³ \$/yr)	<ul style="list-style-type: none"> • Very high mineral content brine • Extraction from post-flash brine • Flow rate of 6,950 gpm • Based on generic brine processing flow-sheet in Exhibits 7 and 8. This processing was assumed to be useable for this brine with elimination of steps for recovery of saline minerals and Br₂. 	20 (1975)
	Br ₂	8.7	1,148		
	NH ₃	30.5	1,107		
	BaSO ₄	10	165		
	Na ₂ B ₄ O ₇ ·10H ₂ O	150	3,465		
	CaCl ₂	4,850 anhydrous			
		12,125 as 40% brine	66,021		
	Fe ₂ O ₃	62	307		
	Li ₂ CO ₃	63	8,316		
	Pb	7	924		
	MnO ₂	116.5	4,998		
	KCl	1,715	22,638		
	NaCl	9,000	17,820		
	SrCO ₃	48	4,752		
sa L-6-1 ine, perial lley	Zn	24.5	6,468	<ul style="list-style-type: none"> • Considered marginal for minerals recovery • Extraction from post-flash brine • Flow rate of 10x10⁶ gal./yr. 	
	Ag	77 lb/day	1,200		
			139,328		
	Br ₂	1.5	198		
	NH ₃	1.7	62		
	CaCl ₂	161.5 anhydrous			
		404 as 40% brine	2,200		
	Li ₂ CO ₃	12.5	1,650		
	SrCO ₃	16	1,584		
	Na ₂ B ₄ O ₇ ·10H ₂ O	9.8	226		
			5,920		

(see Exhibit 3). However, there is no convincing recent evidence of the cost-effectiveness of minerals (or other by-products) production in association with geothermal energy. At this point, it is appropriate to state only that by-product recovery could conceivably be of economic benefit to a geothermal energy project in terms of monetary income and/or reduced cost of waste disposal. Only site-specific studies of specific recoverable materials can meaningfully estimate these benefits.

- (10) Are there any legal or institutional ramifications of geothermal by-product recovery?

The subject of by-product recovery associated with geothermal energy utilization, in a legal context, spans issues from the legal definition of geothermal resources to any special permits which might be required to initiate mineral production.

Although no such situations have arisen, it is not anticipated that a geothermal resource developer who wants to recover minerals from brines in conjunction with energy production will face any burdensome federal permitting process or related regulatory obligations. Under the Geothermal Steam Act of 1970, royalties would be collected on any by-product operations. (28) The Act also apparently made geothermal resources subject to provisions of the Mineral Leasing Act of 1920 (17). The Bureau of Land Management (BLM) would have to be notified by a potential developer, through submission of a plan of utilization, of his intent to recover by-products and BLM would probably authorize such operations under the developer's steam lease (28).

President Reagan's recently unveiled National Materials and Minerals Plan is focussed, in part, on stimulating domestic minerals production, opening up more public lands to minerals exploration, and fostering (through the Bureau of Mines) new policy to give greater consideration to minerals issues in decisions regarding land and water use (32). It is reasonable, therefore, to expect a favorable overall federal attitude towards geothermal brine minerals recovery which might be proposed.

As a producer of chemicals for commercial consumption, the geothermal by-product developer is likely to be subject to the Toxic Sub-

stances Control Act (TSCA). Through a number of regulatory mechanisms established under TSCA, EPA exercises control over the manufacturing, distribution, use, and disposal of harmful and potentially harmful chemical substances. Since it is very unlikely that any new substances will result from geothermal by-product recovery, such operations will probably not fall under the minimum 90-day premanufacture notification and review provisions of TSCA. However, for by-products already known to be hazardous (notably heavy metals), compliance with TSCA could well involve other types of EPA notifications, production and use record-keeping, environmental/health effects identification, and related activities.

One important fundamental legal issue in this area is the technical definition of a geothermal resource, that is, whether it is considered water, mineral, energy, some combination of these, or something entirely different. The federal definition includes any by-products (except oil, hydrocarbon gas, and helium) which may be derived from a reservoir of geothermally-heated fluid. It appears that most significant resource-containing states have adopted a legal definition similar to the federal position in terms of including and/or recognizing non-energy by-products; these states include Alaska, Arizona, California, Hawaii, Montana, Nevada, New Mexico, Oregon, Texas, and Washington. This trend does not prevent a state from adopting a different definition. The most notable examples are Idaho and Montana, which regards geothermal resources as "sui-generis", being neither water nor mineral (even though the Montana definition explicitly identifies hot water, steam, and minerals as components of a geothermal resource). Still other states (generally not important resource

states) have not yet ruled on this issue. How the states will treat commercial mineral recovery from spent geothermal brines in practice remains to be seen.

- (11) What technical and economic problems need to be addressed to establish/improve the feasibility of geothermal by-product recovery?

The major areas of technical uncertainty surround the:

- Characteristics of potential by-product sources (spent brine and other wastes).
- Suitability of modified existing or scaled-up experimental recovery processes for geothermal energy applications.
- Marketability of recovered materials in terms of product quality, quantity, and supply reliability.

The major areas of economic uncertainty surround the:

- Costs of recovery operations
- Market factors relating to product value, demand, "delivery" cost, etc.
- Ability to recoup recovery costs through by-product sale and/or reduced waste disposal cost.

All of these technical and economic issues can be satisfactorily resolved only on a site-by-site basis for particular by-products. Past experience has demonstrated the technical feasibility of recovering at least a few types of materials (e.g., simple chlorides, CO_2 , and H_3BO_3) from geothermal brines. However, routine by-product recovery on a scale commensurate with geothermal power production facilities cannot be easily "engineered up" from the limited operations to date. Furthermore, relative geographic source/consumer locations, fickle market conditions, and alternative supplies for such commodities can individually or conspiratorially render recovery an uneconomic proposition. As apparently experienced by two U.S. companies in the 1960's, changing market conditions can contribute to the downfall of commercial operations once underway (17).

Since by-product recovery associated with geothermal energy plants is currently an undeveloped resource application in this country, there is considerable groundwork to be performed before such operations can be confidently assessed. As with most other site development issues, the feasibility and attractiveness of by-product recovery will be highly site-specific matters which cannot be other than superficially addressed in generic discussions. The thrust of industry and DOE efforts is towards demonstrating and commercializing energy production from geothermal resources. As the major obstacles in energy conversion are overcome, it is reasonable to expect a greater interest in the benefits of by-product recovery in the near future. Industry may then renew and expand attempts to utilize waste products generated at geothermal energy facilities.

Exhibit 22 outlines the significant R&D and information needs that should be addressed in order to properly evaluate and, if appropriate, promote by-product recovery in partnership with geothermal (hydrothermal) energy production. A group of "higher priority" and a group of "lower priority" needs have been distinguished, with no priorities intentionally set within the groups. This grouping is meant only as a relative guide and should not be necessarily interpreted as identifying "high" and "low" priority needs. Most of the activities identified must be performed for each site and combined energy/by-product application under consideration.

EXHIBIT 22

R&D/INFORMATION NEEDS IN THE AREA OF GEOTHERMAL BY-PRODUCTS RECOVERY

HIGHER PRIORITY

- Compilation of up-dated geothermal fluid characteristics at priority sites to more accurately identify potentially-recoverable minerals and their concentrations.
- Up-to-date market studies of specific potentially-recoverable products in specific geographic locations, taking into account the quantity, quality, likely price, and supply reliability of the geothermally-produced material versus that from competing sources.
- More systematic chemical and engineering analysis of current and past commercial operations using geothermal fluids or similar brines for purposes of evaluating selected geothermal energy applications.
- Assessment of experimental (pilot-plant and laboratory) processes for brine minerals extraction in terms of geothermal energy applications, especially the sulfide and hydroxide precipitation processes being investigated by the Bureau of Mines.
- Calculation or up-dating, as necessary, of cost estimates for generic mineral extraction processes.
- Determination of at which geothermal sites spent brine injection will be required and what, if any, pre-injection brine treatment will be needed.
- Monitoring of Bureau of Mines activities in hydrogeothermal mineral recovery and Bureau of Reclamation activities in geothermal brine desalination (although future BOR activity in this area is expected to be curtailed).

LOWER PRIORITY

- Analysis of the legal/regulatory/permitting implications of, and constraints on, mineral recovery in conjunction with geothermal energy utilization.
- Determination of geothermal energy industry attitudes towards by-product recovery.
- Identification of any "secondary" environmental consequences of by-product recovery (e.g., disposal requirements for residual wastes).

- (12) What R&D is being conducted to investigate possible recovery systems?

DOE is not sponsoring any R&D specifically focussing on the recovery of useful by-products from geothermal brine used as an energy source or from associated wastes. However, other organizations have been interested, since the early years of geothermal resource exploration, in the prospects for mineral recovery from geothermal brines. In particular, the U.S. Bureau of Mines (BOM) has been investigating the technical feasibility of such "mining" activities and has long recognized the possibility for utilizing spent brines from geothermal power plants in California's Imperial Valley (17, 7, 25).

BOM has been focussing on chemical precipitation techniques for heavy metals recovery from geothermal brines. This approach was chosen, in part, on the explicit assumption that evaporation-based techniques will not be practicable due to the need to inject withdrawn brines. Therefore, recovery of Na, K, and Ca chlorides has not received attention. BOM has sponsored R&D for two approaches to heavy metals extraction: recovery as hydroxides and recovery as sulfides (25).

Preliminary results of the sulfide precipitation process (being investigated by SRI International) are discussed elsewhere in this issue paper. Generally, 80-90% of the Pb and Zn, 30-40% of the Fe, and 20% of the Mn can be recovered as sulfide. This process has, so far, only been investigated in the laboratory (with Imperial Valley geothermal brines) (25).

Lime treatment to precipitate hydroxides (investigated by Hazen Research, Inc.) generally recovered 90-95% of the Pb, Zn, Li, Fe, and

Mn. A pilot plant was constructed (by WESTEC) near Niland for the purpose of producing these hydroxide precipitates. The pilot-plant process was modeled on the Hazen Research procedure, with slight modification. At the plant (which has been dismantled), post-flash brine was first treated to remove silica, then treated with lime to precipitate minerals, and finally acidified back to pH 5.5 to be injected. It was found that further processing of the obtained precipitates to separate mineral values was more difficult than expected. In particular, only about 50% of the precipitated Zn could be usefully recovered, for reasons as yet unknown. A report on this hydroxide precipitation R&D will not be available until the second half of 1982 (25).

Due to the fact that higher Zn extraction was demonstrated with the alternative sulfidation process and a better product for Zn reduction plants was obtained, BOM has not pursued the problem of low Zn recovery in the hydroxide process. At the present time, BOM has plans to concentrate further R&D on the sulfide recovery process through the end of FY 1983. This effort will finish current Li extraction work and investigate methods to improve sulfide precipitate grain size and to produce a Zn product suitable for industrial Zn reduction (25).

The Bureau of Reclamation (BOR) has been investigating, since 1972, feasibility of producing fresh water from geothermal brine at East Mesa in the Imperial Valley to augment the flow of the lower Colorado River (10). Three different pilot-plant desalination systems have been operated at the site: multistage flash evaporator, vertical tube evaporator, and a high-temperature electrodialysis unit (10, 26). All of these systems were successful, although the multi-stage flash

technique may be preferred due to its relative simplicity and fewer plugging problems. This field work (conducted by Bechtel) was terminated in 1977-78 apparently because it was concluded that even commercial-scale operations could not significantly improve the fresh water supply in the area (26).

Since these East Mesa desalination investigations finished, BOR has contracted work to consolidate the results of all previous studies of geothermal brine desalination and to identify U.S. sites deserving further study (26, 27). Ten such sites have been identified, including El Dorado Valley, NV; Twenty-Nine Palms, CA; Huntington Beach CA; and Springerville, AZ. All of the ten sites are outside of recognized KGRA's. The report of this work will not be released until at least the second half of 1982 (27).

The implications of these geobrine desalination projects for minerals recovery from residuals have not been explicitly studied by BOR (26, 27), although SiO_2 , CaCO_3 , and BaSO_4 scales were deposited in the pilot-plants (10). According to one source (27), BOR is not enthusiastic about geobrine desalination and will not initiate further work.

As far as non-brine sources of by-products in geothermal energy use are concerned, the EIC Company is apparently attempting to alter their H_2S emission abatement system to obtain valuable by-products (31). The EIC process as field tested already recovers NH_3 and H_3BO_3 from geothermal steam.

(13) What is the role of DOE's Geothermal and Hydropower Technologies Division in this area?

The priority concern of DOE/GHTD with geothermal resources remains the exploitation of the energy content of these resources. Concern with minerals recovery occupies a much lower priority. However, since such recovery has the potential for supplementing and enhancing the economic characteristics of resource utilization, it is far-sighted for GHTD to examine the feasibility and potential advantages of by-product recovery. Minerals recovery is more appropriately the purview of the Department of Interior in terms of identifying and assessing minerals resources and investigating recovery technology. Nevertheless, GHTD is interested in all activities that may make geothermal energy resource development more attractive and competitive.

In its capacity as a "front-line" interested party, GHTD should keep up to date with geobrine minerals recovery investigations sponsored by the Department of the Interior and, to the extent publically reported, by industry, GHTD should be prepared to closely monitor developments to determine the implications for geothermal energy projects.

REFERENCES

1. Barnea, J., "Geothermal Minerals - The Neglected Minerals", The Future of Small Scale Mining, First International Conference, UNITAR/SEPAFIN, Jurica, Qro., Mexico, Nov. 26 - Dec 5, 1978.
2. The Geyser, Vol. 7, Issue 17, Oct. 27, 1981.
3. Geraghty and Miller, Inc., Newsletter, Vol. 3, No. 3, 1981.
4. Stringer, J., "Mineral Treasure From The Galapagos Ridge", NOAA, Vol. 12, No. 1, 1982.
- *5. Kingston Reynolds Thom and Allardice, Ltd., Preliminary Survey of Geothermal By-Products, P2430, Oct. 1981.
6. Collins, A.G., "Mineral Brines and Their Utilization Through Small-Scale Mining in the USA", The Future of Small Scale Mining, First International Conference, UNITAR/SEPAFIN, Jurica, Qro., Mexico, Nov. 26 - Dec. 5, 1978.
7. Farley, E.P., et.al., Recovery of Heavy Metals From High Salinity Geothermal Brine, U.S. Bureau of Mines, OFR 91-81, NTIS Report No. PB81-222218, Dec. 1980.
8. The Geyser, Vol.?, Issue ?,.
9. Bjornsson, S., et. al., "Economic Evaluation of Reykjanes Thermal Brine Area, Iceland", J. Am. Assoc. Pet. Geol. Bull., Vol. 56, No. 12, 1972.
10. Lindemuth, T.E., et. al., "Experience in Scale Control With East Mesa Geothermal Brine", 1977 SPE-AIME International Symposium on Oilfield and Geothermal Chemistry, La Jolla, California, June 27-28, 1977 (Paper No. SPE 6605).
11. Nguyen, V.T., et. al., Geothermal Energy Environmental Problems and Control Methods, The MITRE Corporation, DOE/ET/27224-T1, June 1980.
12. Layton, D. (ed.), An Assessment of Geothermal Development in the Imperial Valley of California: Volume 1 - Environment, Health and Socioeconomics, Lawrence Livermore National Laboratory, DOE/EV-0092, July 1980.
13. Morris, W. and Hill, J. (eds.), An Assessment of Geothermal Development in the Imperial Valley of California: Volume 2 - Environmental Control Technology, Lawrence Livermore National Laboratory, DOE/EV-0092, July 1980.

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14. Reeber, R.R., "Coatings in Geothermal Energy Production", Thin Solid Films, Vol. 72, 1980.
15. Hartley, R.P., Pollution Control Guidance for Geothermal Energy Development, EPA-600/7-78-101, June 1978.
16. Howard, J. H., and Towse, D., "History of Exploitation at Salton Sea Geothermal Field, California", Am. Assoc. Pet. Geol. Bull., Vol. 61, No. 5, p. 796, May 1977.
17. Blake, R.L., Extracting Minerals From Geothermal Brines: A Literature Study, U.S. Bureau of Mines Information Circular 8638, NTIS Report No. PB-240681, Dec. 1974. (This report references 67 other sources of information.)
18. Katz, Gerald, U.S. Department of Energy, San Francisco Operations Office, personal communication, April 1981, (415) 273-7943.
19. Sung, R., et. al., Preliminary Cost Estimates of Pollution Control Technologies for Geothermal Developments, Interagency Energy Environment R&D Program Report, EPA-600/7-79-225, Oct. 1979.
20. Berthold, C.E., et. al., Process Technology for Recovering Geothermal Brine Minerals, U.S. Bureau of Mines Report No. OFR 35-75, NTIS Report No. PB-241 867, Feb. 1975.
21. U.S. Bureau of Mines, Mineral Facts and Problems - 1980 Edition, Bureau of Mines Bulletin 671.
22. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Control and Treatment Technology for the Metal Finishing Industry - Sulfide Precipitation, Summary Report, EPA 625/8-80-003, April 1980.
23. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Control Technology for the Metal Finishing Industry - Evaporators, Summary Report, EPA 625/8-79-002, June 1979.
24. U.S. Environmental Protection Agency, Office of Water Planning and Standards, Environmental Regulations and Technology - The Electroplating Industry, EPA 625/10-80-001, August 1980.
25. Schultze, Lawrence, U.S. Bureau of Mines, Reno Research Center, personal communication, April 1982, (702) 784-5394.
26. Fernelius, Wayne, U.S. Bureau of Reclamation, Policy Planning Staff, Washington, D.C., personal communication, April 1982, (202) 343-5275.
27. Esquivel, Cato, U.S. Bureau of Reclamation, Division of Planning, Boulder City Office, personal communication, April 1982, (702) 293-8547.

28. Duscher, Karl, Bureau of Land Management, Division of Mineral and Geothermal Resources, Washington, D.C., personal communication, April 1982, (202) 343-8537.
29. Laird, A.D., et. al., Ranking Research Problems in Geothermal Development, Office of Saline Water, U.S. Department of the Interior, R&D Progress Report No. 711, August 1971.
30. Coury, G.E. and Fritzler, E.A., "Preliminary Process and Cost Analysis of a Multipurpose Geothermal Power and Desalination Plant", Geothermal Resources Council Transactions, Vol. 4, Sept. 1980, pp. 507-10.
31. U.S. Department of Energy, Geothermal Progress Monitor, Report No. 6, June 1982.
32. U.S. Department of the Interior Bureau of Mines, news release, April 29, 1982.
33. Ellis, A.J. and Mahon, W.A.J., Chemistry and Geothermal Systems, Academic Press, New York, 1977.

APPENDIX A

RECOVERY TECHNOLOGY DESCRIPTIONS

FLOCCULATION

Process Description

Flocculation is an essential part of any chemical or chemically aided precipitation system. It involves stirring or agitation to increase the opportunity for particle contact after the chemicals have been added. Increased particle contact will promote floc growth. However, if the agitation is too vigorous, the shear forces that are set up will break up the floc into smaller particles. Agitation should be carefully controlled so that the floc particles will be of suitable size and settle readily.

Two types of flocculation systems are available for wastewater treatment, namely mechanical agitation and aeration. Paddles for mechanical agitator usually have a peripheral speed of about 1.5 feet per second. Sometimes stationary slats or stator blades are installed in the flocculation tanks to break up the mass rotation of fluid and promote mixing. For air agitation systems, porous tubes or diffuser nozzles are used. The amount of air required is approximately 0.10 cubic feet per gallon for a 45-minute detention period. A typical tank design, as shown above, is similar aeration tanks used in many wastewater treatment systems.

Potential Application

Flocculation is used to improve the settling of suspended solids. It can be used in association with chemical precipitation.

SEDIMENTATION

Process Description

Sedimentation is the separation of suspended particles that are more dense than water by gravitational settling. Although the concept of sedimentation is rather simple, many design options are available to increase the efficiency of the operation. Sedimentation tanks are designed on the basis of surface loading rate expressed in gallons per day per square foot of horizontal area. The selection of loading rate depends on the types of suspension to be separated. The surface loading rate together with the depth of the sedimentation tank will determine the detention time of the fluid to be treated.

Most treatment plants now use mechanically cleaned sedimentation tanks of standard circular or rectangular design. A typical tank, as shown above, has a sloped bottom at about 1 inch per foot to form an inverted cone. The sludge is scraped to a relatively small hopper near the center of the tank. Sedimentation tanks can be used by themselves or in conjunction with other treatment processes, particularly chemical precipitation and flocculation.

Potential Application

Spent geothermal fluids typically contain higher amounts of suspended solid relative to raw geothermal fluids mainly because of the decrease in temperature after they pass through the energy conversion system. Sedimentation is probably the most simple and least expensive pre-treatment process.

FLOTATION

Process Description

Flotation is a process used to separate solid or liquid particles from a liquid phase. Separation is brought about by introducing fine gas bubbles into the liquid phase. The bubbles attach to the particulate matter and the buoyant force of the combined particle and gas bubbles causes the particle to rise to the surface. Given particles with a higher density than water can be made to rise. Once the particles have floated to the surface, they can be collected by a skimming operation. The major advantage of flotation over sedimentation is that very small or light particles that settle slowly can be removed more completely and in a short time using the flotation method.

Sometimes chemicals are used to aid the flotation process. These chemicals function to create a surface or a structure that can easily absorb or entrap air bubbles. Aluminum and iron salts, and activated silica are the most common chemicals used.

Potential Application

Flotation can be most effectively applied to fluid systems that contain solids having specific gravity slightly greater than unity. It will have limited application in the geothermal fluid system if precipitation of heavy metal ions is the main concern.

FILTRATION

Process Description

Filtration is generally used following the coagulation-sedimentation process and is designed to further remove the solid particles from the treated water. Filter beds are generally designed with consideration given to the characteristics of the fluid to be treated. The suspended solids concentration; particle size and distribution; and particle changes often determine the types of filter medium to be used.

In recent years, increasing emphasis has been placed on the use of multi medium filter beds. Common filter media includes anthracite, sand, garnet, activated carbon, and weighted spherical resin bed. Since filter performance is related directly to the characteristics of the liquid to be filtered, it is recommended that pilot plant studies be conducted to determine the optimum combination of filter materials.

Potential Application

Filtration is a necessary step following chemical precipitation and sedimentation.

EVAPORATION/DISTILLATION

Process Description

Evaporation/distillation is applicable to many different types of waste treatment and desalination systems. For waste treatment systems, vacuum evaporation can be used to concentrate the dissolved solids by depressing the boiling point of water through the use of a partial vacuum. The water removed can be condensed and reused. In another system, atmospheric evaporation is enhanced by the use of forced air through a chamber into which the fluid is sprayed to accelerate evaporation rate.

For desalination systems, multiple-effects evaporators are used to conserve heat. Steam is introduced to the first effect on the series, and succeeding effects are operated at lower pressure so that steam condensed from the preceding stage can be used as a heat source in the next.

Solar evaporation is another means of removing water. This method is commonly used for the recovery of salt (NaCl) from seawater.

Potentail Application

Because of the inherent high-temperature of spent geothermal fluids, some energy savings can be achieved if evaporation and distillation are used. Residues from the evaporation process will contain a large number of chemical constituents previously present in the geothermal fluid. Extensive processing will still be required before by-products can be recovered.

AIR STRIPPING

Process Description

Air stripping is particularly useful for the removal of ammonia (NH_3). Ammonium ion (NH_4^+) in geothermal fluid exists in equilibrium with NH_3 as shown in the following equation:

As the pH in the fluid is increased above 7, (i.e., more alkaline), the equilibrium is shifted to the left and the NH_4^+ is converted to NH_3 which can be subsequently removed as a gas by agitating the fluid in the presence of air. This is usually accomplished in a packed tray tower equipped with an airblower. Since the solubility of NH_3 in water decreases with increasing temperature, the air stripping process offers advantages to geothermal system because of the inherent higher temperature of geothermal fluid. A 10 degree centigrade increase in fluid temperature may reduce the air requirement by as much as 50%.

A typical air to liquid ratio of 300 cubic feet of air for one gallon of liquid at 20°C is required for effective removal (90+%) of ammonia.

Potential Application

This process is attractive if it is used in conjunction with chemical treatment using lime. Effluents from the lime treatment process will have a pH of about 10-11 which is the ideal range for air stripping.

REVERSE OSMOSIS

Process Description

Reverse osmosis is a process in which water is separated from dissolved salts in solution by filtering through a semipermeable membrane at a pressure greater than the osmosis pressure caused by the dissolved salts in the fluid. Operating pressure ranging from atmospheric to 1,500 psi is generally required to overcome the osmotic pressure.

Most membranes currently in use are cellulose acetate. Under existing manufacturing process, a semipermeable membrane is subject to temperature treatment that sets the rate at which water can be produced. Therefore different membranes have different permeability for various ions. A great drawback of the reserve osmosis system is that the wastewater must not contain precipitated salts or colloidal substances which may deposit on the membrane and greatly reduce its permeability.

Potential Application

While reverse osmosis may be practical for the desalination of brackish waters, it has limited application for the treatment of geothermal fluids, which typically are more saline than brackish water and generally contain suspended solids. Further, the products generated are concentrated brine which will still require further treatment before materials can be recovered.

ELECTRODIALYSIS

Process Description

Electrodialysis is a process by which ionic components of a solution are separated through the use of semipermeable ion-selective membranes. An electrodialysis cell consists of alternate cation and anion permeable membranes arranged in a stack with positively and negatively charged electrodes on each side. The application of an electrical potential between the two electrodes causes the migration of the cations to the negative electrode and anions to the positive electrodes. Because of the alternate spacing of cation and anion permeable membranes, cells of concentrated and dilute salts are formed.

While electrodialysis is found practical for the desalination of brackish waters, it is not very suitable for the treatment of high salinity fluids, primarily because of the high energy requirement. In addition, fouling of the membranes by colloidal matters is a common problem. To reduce membrane fouling, activated carbon treatment, preceded by chemical precipitation and filtration may be required.

Potential Application

The major product of electrodialysis is product water with high purity. The waste product is concentrated fluids which still need to be processed before salts can be recovered. Therefore its application for by-product recovery is somewhat limited.

ION EXCHANGE

Process Description

Ion exchange is a process by which ions of a given species are displaced from insoluble exchange materials by ions of a different species in solution. The exchange material is usually in a synthetic resin placed in a bed or packed in a column, and the water to be treated is passed through it. The chemistry of ion exchange process may be represented by the following equilibrium equation:

where R is the synthetic resin and M is the metallic cation to be removed from solution. As indicated in the above equation, the undesirable cation is removed from the solution and bound to the resin.

After the ability of the resin to pick up the metallic ions has been diminished, the ion exchange column have to be regenerated, usually by backwashing with an acid solution:

The metallic salt, MCl, can be recovered by evaporation or crystallization.

Potential Application

Ion exchange can be designed to selectively remove cations from the solution. However, most ion exchange resins suffer rapid degradation at elevated temperatures. The presence of Na and K ions may also interfere with the heavy metal ion exchange processes.

LEACHING

Process Description

Leaching is a process by which a solvent is added to a mixture of solids so that the sought-after component(s) becomes dissolved in the solvent. Water is the most commonly used solvent, although strong acids, and bases are sometimes used. The simplest process for leaching a solid is the physical process by which the aqueous phase is water and there is no chemical transformation. However, when a solid is dissolved by a chemical reagent in an aqueous phase, ionic and oxidation reactions may occur. For example, aluminum hydroxide is only slightly soluble in water, but in the presence of an acid, its solubility greatly increases:

Dissolution by oxidation followed by complex ion formation is commonly used in the mineral ore extraction process. For example, the overall reaction for extracting gold from its ores, is:

The diagram above illustrated gold heap leaching.

Potential Application

Because of the chemical complexity of geothermal fluids, solids (or sludges) recovered will also be chemically complex. Leaching can be used to selectively recover the desired chemicals or minerals from the sludge.

APPENDIX B

MINERAL DATA SHEETS

Name: Aluminum (Al)

Natural Occurrence:

Aluminum occurs mainly in mines as bauxite, which is a mixture of Al_2O_3 , SiO_2 , Fe_2O_3 , TiO_2

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Aluminum metal is mainly used for construction end-products such as siding, doors, and windows. It is also used in transportation, electrical devices, cans, containers and appliances. Alumina (Al_2O_3) is used as refractories and chemical intermediates.

Cost (Wholesale Price):	Aluminum metal	\$1,200 per ton	(1979)
	Alumina (Al_2O_3)	\$190 per ton	(1980)
	Aluminum Sulfate ($\text{Al}_2(\text{SO}_4)_3$)	\$160 per ton	(1980)
	Aluminum Chloride (AlCl_3)	\$1,000 per ton	(1980)

U.S. Production and Demand:

U.S. production was 420,000 tons in 1979

U.S. demand was 6,640,000 tons in 1979

Strategic Consideration:

- 93% of domestic requirements are met by import
- Domestic bauxite reserves are more difficult to process, relative to foreign bauxite
- Aluminum is one of the first "controlled materials" in the DOC/Defense Materials System

Methods of Commercial Production:

Alumina is produced by caustic leaching of bauxite at elevated temperatures, and followed by selective precipitation as hydrated aluminum oxide ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$).

Aluminum metal is produced by electrolysis of alumina in a molten bath of cryolite (Na_3AlF_6)

Potential for Recovery from Geothermal Resources:

Aluminum can be recovered as hydrated aluminum oxide through the addition of lime.

Name: Arsenic (As)

Natural Occurrence:

Arsenic occurs mainly as a minor constituent in complex ores of copper, lead, zinc, gold, and silver.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Arsenic is mainly used in agricultural chemicals, such as herbicides, plant desiccants and defoliants, insecticides, and soil sterilizers.

Cost (Wholesale Price):

Arsenic Oxide (As_2O_3) \$700 per ton (1980)

U.S. Production and Demand:

U.S. production was about 6,350 tons of contained arsenic in 1979 of which 80% of the ores were imported.

U.S. demand was 16,200 tons of contained arsenic in 1979.

Strategic Consideration:

Despite large import volume, domestic reserves of arsenic are adequate.

Methods of Commercial Production:

Arsenic trioxide is produced as by-products of base-metal ores.

Potential for Recovery from Geothermal Resources:

Arsenic can be recovered from geothermal fluids by the addition of acid ferrous sulfate and coprecipitated with the iron floc.

Name: Barium (Ba)

Natural Occurrence:

Barium occurs mainly as barite (BaSO_4) in bedded and vein deposits.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Barite is used as a weighting material in drilling muds. It is also used as chemical intermediates, and in paints, plastic, glass and rubber.

Cost (Wholesale Price):

Barite Ore	\$25 - \$55 per ton depending on grade	(1979)
Barium Sulfate (BaSO_4)	\$100 per ton	(1981)
Barium Chloride (BaCl_2)	\$300 per ton	(1981)

U.S. Production and Demand:

U.S. production was 2,000,000 tons in 1979

U.S. demand was 3,000,000 tons in 1979.

Strategic Consideration:

- 1,500,000 tons of barites were imported in 1979
- Barium is not in the list of strategic and critical materials
- No foreign country dominates supply

Methods of Commercial Production:

Barite ores are roasted with coal to produce BaS , which is leached with hot water and subsequently precipitated as BaSO_4 .

Potential for Recovery from Geothermal Resources:

Barium can be precipitated as BaSO_4 from geothermal fluids.

Name: Boron (B)

Natural Occurrence:

Boron occurs mainly as borax in lake brines

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Boron is mainly used for the manufacturing of special glass, glass fiber in insulation, coatings, soaps and detergents, and agricultural chemicals.

Cost (Wholesale Price):

Borax pentahydrate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$) \$167 per ton (1979)

U.S. Production and Demand:

U.S. production was 248,000 tons of contained boron in 1979

U.S. demand was 127,000 tons of contained boron in 1979

Strategic Consideration:

- 130,000 tons of boron were exported in 1978
- The supply of boron is adequate to meet domestic and export requirements
- Boron is not a strategic material

Methods of Commercial Production:

Boron in lake brine is recovered by solvent extraction and acidification, followed by dehydration to form boric acid.

Potential for Recovery from Geothermal Resources:

Boron can be recovered from geothermal brine by the addition of sodium compounds. However, better methods to extract boron from brines of low boron concentrations need to be developed.

Name: Bromine (Br)

Natural Occurrence:

Bromine occurs mainly as sodium bromide in brines, saline deposits, salt lakes and sea.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Bromine is mainly converted to ethyl dibromide which is used with tetralthyl lead as gasoline anti knocking agent. Bromine is also used in fire retardants.

Cost (Wholesale Price): Bromine, \$440 per ton (1979)

U.S. Production and Demand:

U.S. production was 250,000 tons in 1979

U.S. demand was 190,000 tons in 1979

Strategic Consideration:

- Supplies of bromine are virtually unlimited
- 50,000 tons of bromine were exported in 1978
- Bromine is not on the list of strategic and critical materials.

Methods of Commercial Production:

Bromine is extracted from brines using chlorine gas. A 95% recovery is attainable.

Potential for Recovery from Geothermal Resources:

The same brine extraction methods are applicable to geothermal fluids.

Name: Cadmium (Cd)

Natural Occurrence:

Cadmium occurs mainly as impurities in zinc ores.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Cadmium is used in coatings, platings, batteries, pigments, plastics, and synthetic products.

Cost (Wholesale Price): Cadmium metal \$6,000 per ton (1980)

U.S. Production and Demand:

U.S. production was 900 tons in 1979

U.S. demand was 4,900 tons in 1979

Strategic Consideration:

- 2,570 tons of cadmium metal and 830 tons of cadmium ores were imported in 1979
- Cadmium is included in the National Stockpile program.

Methods of Commercial Production:

Cadmium is recovered as by-products of zinc ore.

Potential for Recovery from Geothermal Resources:

Cadmium can be precipitated as $\text{Cd}(\text{OH})_2$ or CdS in geothermal fluids through the addition of lime or sodium sulfide.

Name: Calcium (Ca)

Natural Occurrence:

Calcium occurs mainly as limestone (CaCO_3) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Lime is used as chemical intermediates, construction materials and agricultural chemicals. Gypsum is mainly used as building materials such as interior walls, partitions, and ceilings.

Cost (Wholesale Price):	Limestone, mainly CaCO_3	\$3.00 per ton	(1979)
	Quicklime (CaO)	\$40 per ton	(1979)
	Hydrated Lime (Ca(OH)_2)	\$47 per ton	(1979)
	Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)	\$7.00 per ton	(1979)

U.S. Production and Demand:

U.S. production was 36 million tons in 1979

U.S. demand was 44 million tons in 1979

Strategic Consideration:

- About 40% of gypsum is imported
- U.S. production of limestone meets U.S. demand
- There are no supply problems for gypsum and lime

Methods of Commercial Production:

Since both limestone and gypsum occur in the natural state only minor processing is required to remove impurities.

Potential for Recovery from Geothermal Resources:

Calcium can be precipitated as carbonate from geothermal brines.

Name: Cesium (Ce)

Natural Occurrence:

Cesium occurs mainly as pollucite, an ore that contains approximately 25% cesium oxide (Cs_2O).

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Cesium is used mainly in chemicals, medical, electrical and electronic applications, and research and development such as liquid metal in MHD systems.

Cost (Wholesale Price):

Cesium ore (pollucite)	\$2,000 per ton	(1979)
Cesium compounds	\$58,000 to \$74,000 per ton	(1979)
Cesium metal (99.9%)	\$600,000 per ton	(1979)

U.S. Production and Demand:

U.S. production is negligible

U.S. demand was 14 tons in 1979

Strategic Consideration:

- Despite 100% imported, cesium supply is considered to be adequate.

Methods of Commercial Production:

High purity cesium is produced by reacting it at red heat with a metal. It can also be produced by electrolysis of fused cesium salt.

Potential for Recovery from Geothermal Resources:

Since all common compounds of cesium are soluble, recovery from geothermal fluid will have to be done by evaporation.

Name: Chromium (Cr)

Natural Occurrence:

Chromium occurs mainly in ores as chromites (CrO_2^-)

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Chromium is used in the production of stainless steels, heat and corrosion resistant materials, special purpose alloys, pigments, metal plating, leather tanning, chemicals and refractories for metallurgical furnaces.

Cost (Wholesale Price):

Chromium ore \$135 per ton of contained chromium (1979)

U.S. Production and Demand:

U.S. production of chromium has been negligible.

U.S. demand of chromium was 550,000 tons in 1980.

Strategic Consideration:

- All domestic requirements are met by imports.
- Chromium is being stockpiled, these stockpiles represent about a three-year emergency supply.

Methods of Commercial Production:

Chromium is converted to chromium alloys by pyrometallic techniques. It can also be recovered from industrial wastes, particularly metallurgical solutions.

Potential for Recovery from Geothermal Resources:

Chromium can be precipitated as chromium sulfide from geothermal brine.

Name: Cobalt (Co)

Natural Occurrence:

Cobalt occurs mainly in the ores of nickel and copper.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Cobalt is used in aircrafts as superalloys for the production of jet engine parts. Cobalt is also an important constituent in machine tools that require high strength and abrasion resistance. It is used for the production of magnets, paints, chemicals, ceramics, and glasses.

Cost (Wholesale Price):

Cobalt metal \$50,000 per ton (1980)

U.S. Production and Demand:

U.S. production was 585 tons in 1979.

U.S. demand was 6,350 tons in 1979.

Strategic Consideration:

- 94% of U.S. demand of cobalt was imported
- Cobalt is considered a critical material and is currently stockpiled in the National Security Stockpile.

Methods of Commercial Production:

The ore is roasted and leached with ammonia or sulfuric acid, and followed by chemical precipitation. Electrolytic reduction is also common.

Potential for Recovery from Geothermal Resources:

Cobalt can be precipitated as the hydroxide or sulfide.

Name: Copper (Cu)

Natural Occurrence:

Copper mainly occurs as a sulfide deposits. The common ones are chalcopyrite (CuFeS_2), Chalcocite (Cu_2S), bornite (Cu_5FeS_4), covellite (CuS), and enargite (Cu_3AsS_4)

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Copper is mainly used in electrical equipment and supplies. It is also used in construction, machinery, and transportation.

Cost (Wholesale Price):

Copper metal \$2,200 per ton (1980)

U.S. Production and Demand:

U.S. production was 1,986,000 tons in 1979.

U.S. demand was 2,400,000 tons in 1979.

Strategic Consideration:

- Net import is 13%.
- Copper is considered as a strategic material and is being stockpiled. The 1980 stockpile goal for copper is 0.91 million.

Methods of Commercial Production:

Oxide ores are leached in the sulfuric acid. The copper is then recovered from the leached solution chemical precipitation or by electrodeposition.

Potential for Recovery from Geothermal Resources:

Copper can be precipitated as the hydroxide or sulfide.

Name: Fluorine (F_2)

Natural Occurrence:

Fluorine occurs mainly as the mineral fluorite (CaF_2)

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Fluorine is used in the chemical industry and in the production of aluminum and steel. Other uses include water fluoridation and as additive in glasses, enamels and potteries.

Cost (Wholesale Price):

Fluorspar (CaF_2) \$100 per ton (1979)

U.S. Production and Demand:

U.S. production was 88,000 tons in 1979.

U.S. demand was 557,000 tons in 1979.

Strategic Consideration:

- 534,000 tons were imported, mostly from Mexico, in 1979.
- The National Stockpiling system includes fluorspar

Methods of Commercial Production:

Ceramic and acid grades of fluorspar is produced by froth flotation.

Potential for Recovery from Geothermal Resources:

There is no easy method of recovering fluorine from an aqueous solution.

Name: Iodine (I_2)

Natural Occurrence:

Iodine mainly occurs in brines and in sea water.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Iodine is mainly used as chemical intermediates, pharmaceuticals, food products, ink and colorants, sanitary preparations and photographic products.

Cost (Wholesale Price):

Iodine (I_2) \$13,600 per ton (1980)

U.S. Production and Demand:

U.S. production was 1,250 tons in 1979.

U.S. demand was 4,400 tons in 1979.

Strategic Consideration:

- About 3100 tons of iodine were imported in 1979.
- Iodine is being stockpiled with a goal of 5.8 million pounds.

Methods of Commercial Production:

Iodine is produced by chlorine oxidation followed by vapor stripping.

Potential for Recovery from Geothermal Resources:

The same commercial method can be used.

Name: Iron (Fe)

Natural Occurrence:

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Iron is mainly used for the manufacturing of different types of iron and steel.

Cost (Wholesale Price):

Iron ore - \$54 per ton of contained iron in iron ore.

U.S. Production and Demand:

U.S. production was 60 million tons of contained iron in iron ore.

U.S. demand was 180 million tons of contained iron in iron ore.

Strategic Consideration:

- Approximately 33% of iron are imported.
- Developing of domestic supply is possible but is capital intensive and require long lead time (8 years).

Methods of Commercial Production:

Iron is usually refined in the blast furnace.

Potential for Recovery from Geothermal Resources:

Iron can be recovered as the hydroxide or sulfide.

Name: Lead (Pb)

Natural Occurrence:

Lead mainly occurs as ores in association with zinc.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Lead is mainly used in transportation (storage battery), as a gasoline additive and in paints and pigments.

Cost (Wholesale Price):

Lead metal \$860 per ton (1980)

U.S. Production and Demand:

U.S. production, including recycling of old scrapes, 1,100,000 tons.

U.S. demand 1,400,000 tons.

Strategic Consideration:

- Approximately 225,000 tons were imported in 1979.
- Lead is a strategic and critical material and is one of the stockpiled metals.

Methods of Commercial Production:

Lead is smelted in a blast furnace, followed by refining to produce 99.9% lead.

Potential for Recovery from Geothermal Resources:

Lead can be recovered as the hydroxide or sulfide

Name: Lithium (Li)

Natural Occurrence:

Lithium occurs as spodumene ($\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$) and as lithium chloride (LiCl) in brine.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Lithium is used in the production of aluminum, chemicals, glass, lubricants and pharmaceutical products.

Cost (Wholesale Price):

Lithium carbonate (Li_2CO_3)	\$2,600 per ton	(1979)
Lithium hydroxide ($\text{LiOH} \cdot \text{H}_2\text{O}$)	\$3,400 per ton	(1979)
Spodumene	\$4,600 per ton of contained lithium	

U.S. Production and Demand:

U.S. production (information withheld).

U.S. demand 3,200 tons in 1979.

Strategic Consideration:

- Approximately 2,000 tons of lithium were exported.
- U.S. is self sufficient in lithium and plans to continue to capture the world market.

Methods of Commercial Production:

Lithium carbonate is manufactured from spodumene by calcining and then heating with sulfuric acid to form Li_2SO_4 . Reaction with lime produces Li_2CO_3 .

Lithium carbonate is manufactured from brine after concentrating by solar evaporation, followed by treatment with lime.

Potential for Recovery from Geothermal Resources:

Lithium can be recovered as lithium aluminate (LiAlO_2).

Name: Magnesium (Mg)

Natural Occurrence:

Magnesium occurs as dolomite, a mixture of calcium and magnesium carbonate, and in seawater, wells, and lake brines.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Cost (Wholesale Price):

Magnesium metal	\$2,000 per ton
Magnesia (MgO)	\$200 to \$1,000 per ton
Other magnesium compounds	

U.S. Production and Demand:

U.S. production was 1,150,000 tons of magnesium in 1979.

U.S. demand was 1,100,000 tons of magnesium in 1977.

Strategic Consideration:

In 1970, magnesium metal was removed from the list of strategic and critical materials and stockpiling was abolished.

Methods of Commercial Production:

Seawater is mixed with a slurry of calcium hydroxide, product magnesium hydroxide, which is then neutralized to form magnesium chloride. Magnesium metal is produced by the electrolysis of magnesium chloride.

Potential for Recovery from Geothermal Resources:

Magnesium can be recovered as hydroxide.

Name: Manganese (Mn)

Natural Occurrence:

Manganese occurs as ores in association with iron and silicon.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Manganese is mainly used for the production of iron and steel.

Cost (Wholesale Price):

Manganese ore \$1.50 per ton (1980)

U.S. Production and Demand:

U.S. production was 31,000 tons in 1979.

U.S. demand was 1,250,000 tons in 1979.

Strategic Consideration:

- Approximately 880,000 tons of manganese ores and metals were imported in 1978.
- Continued maintenance of the National Strategic Stockpile is essential for the assurance of supply.

Methods of Commercial Production:

Standard pyrometallurgical processes that include roasting and magnetic separation are required for the production of manganese.

Potential for Recovery from Geothermal Resources:

Manganese can be precipitated as hydroxide or sulfide.

Name: Mercury (Hg)

Natural Occurrence:

Mercury mainly occurs as cinnabar ore.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Cost (Wholesale Price):

Mercury metal \$10,500 per ton .

U.S. Production and Demand:

U.S. production was 1,285 tons in 1979.

U.S. demand was 1,725 tons in 1979.

Strategic Consideration:

- About 40% of the mercury demand is imported.
- Mercury has been stockpiled under the Strategic and Critical Materials Stockpiling Act.

Methods of Commercial Production:

Mercury is extracted from ores by heating in furnace to liberate the metal vapor, which was then cooled to produce mercury metal.

Potential for Recovery from Geothermal Resources:

Mercury can be precipitated as the hydroxide or sulfide.

Name: Molybdenum (Mo)

Natural Occurrence:

Molybdenum exists mainly in low grade deposits of the mineral molybdenite (MoS_2).

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Molybdenum is mainly used for metallurgical applications, particularly in steels, cast iron, super alloys and other alloys. It is also used as a chemical intermediate.

Cost (Wholesale Price):

Molybdenum metal	\$12,000 per ton
Molybdenum oxide (MoO)	\$7,000 per ton

U.S. Production and Demand:

U.S. production was 72,000 tons in 1979.

U.S. demand was 37,000 tons in 1979.

Strategic Consideration:

- About 35 tons of molybdenum were exported in 1979.
- Molybdenum is a strategic material. However, because of adequacy of domestic supply, it is no longer stockpiled.

Methods of Commercial Production:

Molybdenum is recovered in ores through floatation. Molybdenum metal is produced by reacting molybdic oxide with hydrogen.

Potential for Recovery from Geothermal Resources:

Molybdenum can be precipitated as hydroxide or sulfide.

Name: Nickel (Ni)

Natural Occurrence:

Nickel is found as an ore containing nickel-copper sulfide, nickel silicates and nickel laterites and serpentines.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

More than 90% of the nickel is used in the form of metal, principally in alloys. Nickel and its compounds are also used in the manufacturing of chemicals.

Cost (Wholesale Price):

Nickel metal - \$5,000 per ton

U.S. Production and Demand:

U.S. production (mines and scraps) was 69,000 tons in 1979.

U.S. demand was 200,000 tons in 1979.

Strategic Consideration:

- Approximately 65% of nickel were imported.
- The stockpile goal for nickel is 200,000 tons.

Methods of Commercial Production:

Nickel sulfide ores are roasted to produce oxides which are in turn processed by smelting to produce ferronickel. It can also be leached with ammonia or sulfuric acid.

Potential for Recovery from Geothermal Resources:

Nickel can be precipitated as hydroxide or sulfide.

Name: Phosphorus (P)

Natural Occurrence:

Phosphorus mainly occurs as phosphate rocks, which are mainly $\text{Ca}_5(\text{PO}_4)_3\text{F}$ and $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Phosphorus compounds are mainly used as phosphate fertilizers. Smaller quantities are used in detergents, feed phosphates and insecticides.

Cost (Wholesale Price):

Phosphate rock \$19 per ton (1979)

U.S. Production and Demand:

U.S. production was 51,000,000 tons (1979).

U.S. demand was 38,000,000 tons (1979).

Strategic Consideration:

- Phosphates are being exported.
- There are no known substitutes for phosphate rocks from which fertilizers are made; by 2015, U.S. supply will balance U.S. consumption.
- Phosphates are not being stockpiled.

Methods of Commercial Production:

Potential for Recovery from Geothermal Resources:

Phosphates can be recovered from geothermal brine through the addition of lime or alum.

Name: Potassium (K)

Natural Occurrence:

Potassium occurs in marine evaporates, brines, and seawater.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Potassium is used as one of the major ingredients in inorganic fertilizers.

Cost (Wholesale Price):

Potash (K_2O) \$117 per metric ton of K_2O equivalent

U.S. Production and Demand:

U.S. production was 2,225,000 metric tons in 1979.

U.S. demand was 6,900,000 metric tons in 1979.

Strategic Consideration:

- Most of the import of potassium comes from Canada.

Methods of Commercial Production:

Solar evaporation is used in potassium-rich brine plants.

Potential for Recovery from Geothermal Resources:

Potassium can be recovered by evaporation of brine.

Name: Sodium (Na)

Natural Occurrence:

Sodium occurs mainly in nature as salt, sodium chloride (NaCl), which occurs in brines, seawater, and rock formations.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Salt is used in food products and is also used for the manufacturing of chemicals. Other uses of salt includes de-icing, drilling mud additive, water treatment, etc.

Cost (Wholesale Price):

Salt in brine	\$4.50 per ton	(1979)
Rock Salt	\$10.00 per ton	
Solar salt	\$12.16 per ton	
Pan salt	\$61.60 per ton	

U.S. Production and Demand:

U.S. production was 46,000,000 tons of salt in 1979.

U.S. demand was 50,000,000 tons of salt in 1979.

Strategic Consideration:

- There are sufficient resources of salt to meet current and projected demand.

Methods of Commercial Production:

Solar evaporation is the most common method used for the recovery of salt (NaCl)

Potential for Recovery from Geothermal Resources:

Sodium chloride can be recovered by evaporation.

Name: Selenium (Se)

Natural Occurrence:

Selenium substitutes ionically for sulfur in many copper iron and lead sulfide minerals.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Selenium is used in electronic components and in photoelectric and xerographic copying applications. It is also used in glass manufacturing, in steel production, manufacturing of rubber and as a dietary supplement in animal feed.

Cost (Wholesale Price):

Selenium \$22,000 per ton

U.S. Production and Demand:

U.S. production was 340 tons in 1979.

U.S. demand was 410 tons in 1979.

Strategic Consideration:

- Selenium is not stockpiled.

Methods of Commercial Production:

Selenium is recovered from copper anode slimes by masting the slime with sulfuric acid and sodium sulfate. Selenium oxide is recovered from the roaster exhaust.

Potential for Recovery from Geothermal Resources:

Name: Silicon (Si)

Natural Occurrence:

Silicon occurs mainly as silica (SiO_2) or silicates, which occur as quartz, quartzite, and sandstone.

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Ferrosilium is used by the iron and steel industry. Silicon is used to produce sil.

Cost (Wholesale Price):

Silicon metal	\$1200 per ton	(1979)
Ferrosilican	\$840 per ton of contained silicon	(1979)

U.S. Production and Demand:

U.S production was 614,000 tons in 1979.

U.S. demand was 708,000 tons in 1979.

Strategic Consideration:

- 80,500 tons of silicon carbide has been stockpiled.
- No other silicon compounds are being stockpiled because of the domestic availability of resources and processing capability.

Methods of Commercial Production:

Ferrosilican and silicon are produced through the pyrometallurgical process. Hydrogen reduction is required for the production of high grade silicon.

Potential for Recovery from Geothermal Resources:

Silicon can be recovered as calicium silicate (CaSiO_3) through the addition of lime.

Name: Strontium (Sr)

Natural Occurrence:

Strontium is found as celestite (SrSO_4) and strontionite (SrCO_3) deposits in the form of bed, vein, modules or masses in sands, clays, shales or dolomitic

Occurrence in Geothermal Fluids (mg/l):

Major End Use:

Strontium is used as electronic components, pyrotechnic materials, ceramics, galss and for the production of nonferrous metals.

Cost (Wholesale Price):

Strontium Carbonate (SrCO_3)	\$580 per ton	
Celestite	\$54 per ton	(1978)

U.S. Production and Demand:

U.S. production was negligible.

U.S. demand was 22,100 tons of contained strontium in 1979.

Strategic Consideration:

- About 90 % of the imported strontium canes from Mexico as celestite.
- Strontium is no longer stockpiled.

Methods of Commercial Production:

Strontium is digested in a hot sodas ash solution to produce strontium carbonate which is then treated with the appropriate acids to produce the various salts.

Potential for Recovery from Geothermal Resources:

Strontium can be precipitated as carbonate or sulfate.

APPENDIX C

ASSESSMENT OF MARKETABILITY OF
GEOTHERMAL BY-PRODUCTS

As summarized in the main report, the information contained in Exhibits 12, 13, and 14 and in Appendix B has been collectively considered, along with a few other factors, to identify a preliminary list of promising and unpromising geothermal by-products (see Exhibit 16). The factors taken into account which have already been covered are:

- Quantity and form of material producible from a "best-case" 50 MWe geothermal power plant
- "Absolute" product monetary value
- U.S. demand for commodity (ignoring regional demands where they exist)
- Import dependency
- Strategic characteristics of the market

Additional factors considered include:

- Technological readiness of recovery process
- Resource uncertainty
- Existing sources of supply (competition)

It should be recognized that a high brine-minerals content does not necessarily imply a high mineral-product value. The case for Rb is a good illustration of this. The "best-case" 50 MWe geothermal power plant would produce 720 times the current U.S. demand for this material (about 1 ton/year). Therefore, Rb compounds, despite their high intrinsic value, will not be a viable product of geothermal minerals recovery. Similarly, recovery of Cs would not be as attractive as the mineral value indicates because of the low market demand (14 tons/year).

Based on such considerations, minerals with values exceeding \$100,000/year were classified as:

- Promising
- Marginally promising
- Speculative
- Not promising.

The rationale for this grouping is given in the following discussion on a product-by-product basis.

PROMISING MATERIALS

- Lithium is considered to be very promising for recovery from geothermal fluids, primarily because of its high mineral value as Li_2CO_3 (\$20,000,000/year) and because recovery of Li by the addition of aluminum oxide to produce lithium aluminate appears to be promising. Lithium is currently extracted from brine and from the ore spodumene. The lithium aluminate process needs to be improved so as to compete with brine extraction processes.
- Boron has a relatively high mineral value (\$5,340,000/year) and can be recovered from geothermal fluids as borax by the addition of sodium compounds. This process is similar to the current method of commercial production and, thus, recovery technology is already demonstrated. However, B is currently being exported. Marketing of B from geothermal fluids will face stiff competition from alternate sources of production.
- Carbon dioxide can be easily recovered from geothermal brines using technologies similar to conventional commercial production. Its mineral value, at \$304,000/year, is very marginal. The added cost of shipping carbon dioxide (as dry ice or compressed gas) over long distances will probably restrict CO_2 produced from geothermal fluid to local markets. Carbon dioxide can also be used on site in the drilling process to control the acidity of drilling mud.
- Ammonia can be recovered through the air stripping process. Although its mineral value is marginal (\$176,000/year), it can be recovered in relatively high quantities. Thus, NH_3 may be able to penetrate small local markets.
- Bromine can be recovered from geothermal fluid through the addition of chlorine gas. This process is the same as the commercial production process which recovers Br_2 from lake brines. Bromine from geothermal resources will face stiff competition from conventional sources.
- Iodine can be recovered in a similar method as bromine. However, the 40 ppm of iodine in brine is probably optimistic. "Typical" values may be substantially lower.

- Heavy Metals (Ni, Cu, Pb, Fe, Zn, and Mo) are either strategic materials or imported to a large degree. With the exception of Mo (\$5,110,000/year), their mineral values are marginal. However, these heavy metals can be collectively precipitated as hydroxides or as sulfides, thereby reducing costs in the primary recovery process.
- Strontium can be recovered as SrCO_3 from spent geothermal fluids, although some of the compound may be deposited as scale during the energy conversion process. Sr is also attractive because of its relatively high mineral value (\$3,600,000/year) and because of the fact that the U.S. requirement is almost exclusively met by imports. Sr recovered from a best-case 50 MWe plant will be able to meet 16% of the U.S. demand. The process technology for Sr recovery needs to be further improved, though.

MARGINALLY PROMISING

- Magnesium is currently recovered from seawater which has a mineral content of 1,350 ppm. Except for the Salton Sea, most geothermal resources have Mg contents substantially less than seawater. The same process for extracting Mg from seawater is applicable to geothermal fluids.
- Aluminum can be extracted as hydroxide through the addition of lime. The solubility of $\text{Al}(\text{OH})_3$ is higher than those of heavy metal hydroxides, reducing the overall efficiency of aluminum precipitation. Recovery from geothermal fluid still warrants consideration because of the large import dependency of this critical material.
- Barium can be precipitated as BaSO_4 . Process technology needs to be improved to increase efficiency of precipitation. BaSO_4 is used as a weighting material in drilling muds and, thus, some of the recovered product may be utilized on-site.

SPECULATIVE

- Gold has a mineral value of \$83,000,000/year. However, this value is derived from one datum point. The uncertainty of Au content in geothermal fluids makes estimating the recovery potential of this valuable mineral a speculative endeavor.
- Silver may appear to be a good compromise to Au. However, its mineral value is relatively small, making its recovery somewhat unattractive. The Ag content in geothermal fluids needs to be further monitored to reduce the uncertainty of this mineral resource.

NOT PROMISING

- Rubidium would not be marketable because of the low U.S. demand: one best-case 50 MWe geothermal power plant will produce enough Rb to supply 720 times the U.S. requirement.
- Cesium is not a good mineral to market because of its low market demand.
- Sodium, as NaCl (salt), is unattractive because the only viable technology for recovery is through solar evaporation. In many jurisdictions, injection of spent geothermal fluids is required, which limits the use of brine evaporation. In addition, there are ample supplies of salt from seawater and other brines.
- Potassium is not an attractive mineral to recover because evaporation is required. It will also face competition from conventional sources such as marine evaporates, brines, and seawater. A majority of the K requirement is met by import from Canada, which will not be threatened.
- Calcium will most likely be precipitated as CaCO_3 scale in the energy conversion plant. There is also ample supply of CaCO_3 as limestone.
- Silicon will most likely be precipitated as silica scale in the plant. Further, the value of silicates are very much dependent on their quality.

APPENDIX D

LIST OF CHEMICAL SYMBOLS AND NAMES

SYMBOL	NAME	SYMBOL	NAME
Aluminum Compounds		Chromium Compounds	
Al	Aluminum	Cr	Chromium
AlCl ₃	Aluminum chloride	Cr(OH) ₃	Chromic acid
Al ₂ (SO ₄) ₃	Aluminum sulfate	Cobalt Compounds	
Al ₂ O ₃	Aluminum oxide	Co	Cobalt
Arsenic Compounds		Co(OH) ₂	Cobalt hydroxide
Ar	Arsenic	CoS	Cobalt sulfide
Ar ₂ O ₃	Arsenic oxide	Copper Compounds	
Barium Compounds		Cu	Copper
Ba	Barium	CuO	Copper oxide
BaCl ₂	Barium chloride	Cu(OH) ₂	Copper hydroxide
BaSO ₄	Barium sulfate	CuS	Copper sulfide
Boron Compounds		Fluorine Compounds	
B	Boron	F ₂	Fluorine
H ₃ BO ₃	Boric acid	CaF ₂	Calcium fluoride
Na ₂ B ₄ O ₇	Borax	Gold Compounds	
Bromine Compounds		Au	Gold
Br ₂	Bromine	Iodine Compounds	
NaBr	Sodium bromide	I ₂	Iodine
Cadmium Compounds		NaI	Sodium iodide
Cd	Cadmium	Iron Compounds	
CdO	Cadmium oxide	Fe	Iron
Cd(OH) ₂	Cadmium hydroxide	Fe ₂ O ₃	Ferric oxide
Calcium Compounds		Fe(OH) ₃	Ferric hydroxide
Ca	Calcium	FeS	Ferrous sulfide
CaCl ₂	Calcium chloride	Fe ₂ S ₃	Ferric sulfide
CaF ₂	Calcium fluoride	Lead Compounds	
CaO	Calcium oxide	Pb	Lead
Ca(OH) ₂	Calcium hydroxide	PbO	Lead oxide
CaCO ₃	Calcium carbonate	Lithium Compounds	
CaSO ₄	Calcium sulfate	Li	Lithium
Carbon Compounds		LiCl	Lithium chloride
CO ₂	Carbon dioxide	Li ₂ CO ₃	Lithium carbonate
CH ₃ OH	Methanol	LiAlO ₂	Lithium aluminate
Cesium Compounds		Magnesium Compounds	
Cs	Cesium	Mg	Magnesium
CsCl	Cesium chloride	MgCl ₂	Magnesium chloride
CsCO ₃	Cesium carbonate	MgCO ₃	Magnesium carbonate
		MgO	Magnesium oxide
		Mg(OH) ₂	Magnesium hydroxide

SYMBOL	NAME	SYMBOL	NAME
Manganese Compounds		Sodium Compounds	
Mn	Manganese	Na	Sodium
MnO	Manganese oxide	Na ₂ CO ₃	Sodium carbonate
M(OH) ₂	Manganese hydroxide	Na ₂ S	Sodium sulfide
MnS	Manganese sulfide	NaHS	Sodium bisulfide
MnBO ₃	Manganese borate	NaOH	Sodium hydroxide
Mercury Compounds		Na ₂ SO ₄	Sodium sulfate
Hg		NaCl	Sodium chloride
Hg(OH) ₂		Strontium	
HgS		Sr	Strontium
Nickel Compounds		SrCO ₃	Strontium carbonate
Ni	Nickel	SrSO ₄	Strontium sulfate
Ni(OH) ₂	Nickel hydroxide	Sulfur Compounds	
NiS	Nickel sulfide	S	Sulfur
Nitrogen Compounds		H ₂ S	Hydrogen sulfide
N ₂	Nitrogen	H ₂ SO ₄	Sulfuric acid
NH ₃	Ammonia	Na ₂ SO ₄	Sodium sulfate
NH ₄ Cl	Ammonium chloride	Titanium Compounds	
(NH ₄) ₂ CO ₃	Ammonium carbonate	Ti	Titanium
Phosphorous Compounds		TiO ₂	Titanium oxide
P	Phosphorus	Vanadium Compounds	
Na ₃ PO ₄	Sodium phosphate	V	Vanadium
Potassium Compounds		V ₂ O ₅	Vanadium oxide
K	Potassium	Tungstun Compounds	
KCl	Potassium chloride	W	Tungstun
KOH	Potassium hydroxide	Zinc Compounds	
Rubidium Compounds		Zn	Zinc
Rb	Rubidium	Zn(OH) ₂	Zinc hydroxide
RbCl	Rubidium chloride	ZnS	Zinc sulfide
Selenium Compounds			
Se	Selenium		
H ₂ Se	Hydrogen selenide		
Silicon Compounds			
Si	Silicon		
SiO ₂	Silica		
CaSiO ₃	Calcium silicate		
Silver Compounds			
Ag	Silver		
AgS	Silver sulfide		

APPENDIX E

BIBLIOGRAPHY

This appendix contains:

- A bibliographic listing of manually-identified literature sources.
- Citations (with abstracts in most cases) to selected reports and current R&D projects identified through an interactive on-line search of the commercial DIALOG computerized literature searching service.

The sources in this appendix were not specifically utilized in the preparation of this issue paper, but they may provide supplemental information to support DOE/DHTD decisions in the area of geothermal by-product recovery. Sources which were identified through the on-line search and utilized for this document are included in the references.

1. Bartlett, R.W., et. al., Extraction of Nonferrous Metals From High Salinity Brine - Geothermal Brine By Sulfide Precipitation, American Institute of Metallurgical Engineers meeting, Las Vegas, Nevada, Feb. 1980.
2. Bartlett, R.W., et. al., "Sulfide Precipitation of Heavy Metals From High Salinity Geothermal Brines", Geothermal Resources Council Transactions, Vol. 3.
3. Buisson, D.H., "Removal of Arsenic From Geothermal Discharge Waters By Absorption On To Iron-Floc and Subsequent Recovery of the Floc", Australian and New Zealand Association For The Advancement of Science, Abstracts, Jan. 22, 1979.
4. Pacific Gas and Electric Co., Demonstration of EIC's Copper Sulfate Process for Removal of Hydrogen Sulfide and Other Trace Contaminants From Geothermal Steam at Turbine Inlet Temperatures and Pressures, DOE/RA/27181-01, May 1980.
5. Aggett, J. and Aspell, A.C., "Release of Arsenic From Geothermal Sources in the Waikato Catchment", 13th Annual Conference on Trace Substances in Environmental Health, Columbia, MO, June 4, 1979.
6. Christensen, D.C. and McNeese, J.A., "Removal of Arsenic and Boron From Geothermal Brines", Proceedings of the 32nd Industrial Waste Conference, Lafayette, IN, May 10, 1977.
7. Rigdon, L., Defluoridation Study for Boise Geothermal Water, Lawrence Livermore Laboratory, UCID-18646, June 3, 1980.

8. Hill, J. H. and Fulk, M.M., Improvements in Geothermal Electric Power and Silica Production, U.S. Patent Application 018,198.
9. Lindal, B., Pilot Plant for Salt Extraction from Geothermal Brine at Reykjanes Iceland, paper to be presented at International Conference on Geothermal Energy, Florence, Italy, May 11-14, 1982.
10. Ellis, A.J. and Mahon, W.A.J., Chemistry and Geothermal Systems, Academic Press, New York, 1977.
11. Dahl, M.M. and Boegli, W.J., Design and Cost of Desalting Processes for the East Mesa Geothermal Resource, Engineering and Research Center, U.S. Bureau of Reclamation, Denver, Colorado.
12. Fernelius, W.A. and Fulcher, M.K., "East Mesa Geothermal Test Site", American Society of Civil Engineers, Environmental; 105: 13-32, February 1979.
13. Riley, W.D., et.al., Well Engineering and Sampling Variables in the Evaluation of Geobrines, U.S. Bureau of Mines Report of Investigations 8465, 1980.

A SURVEY OF SALINE GROUND WATER AS A MINERAL RESOURCE

SUMMERS, W. K.; SCHWAB, G. E.

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES; AND NEW MEXICO INST. OF MINING AND TECHNOLOGY, SOCORRO.

IN: SALINE WATER, MATTOX, R. B. (ED.), AAAS, COMMITTEE ON DESERT AND ARID ZONE RESEARCH, CONTRIBUTION NO 13, P 31-45, 1970. 1 TAB, 7 REF..

Journal Announcement: SWRA0504

SALINE GROUND WATER HAS OFTEN BEEN EXPLOITED AS A SOURCE OF FRESH WATER WITH WASTE MINERAL BYPRODUCTS, BUT THIS CONCEPT HAS GRADUALLY CHANGED INTO ONE OF MINING FOR MINERAL VALUE WITH POTABLE WATER AS A BONUS. VARIOUS DEFINITIONS AND CLASSIFICATIONS OF SALINE WATER ARE REVIEWED. IN GENERAL, SALINE GROUND WATERS OCCUR IN ONLY A FEW GEOLOGIC SETTINGS: SEDIMENTARY BASINS, STRUCTURAL TROUGHS, THERMAL AREAS AND MISCELLANEOUS ISOLATED AREAS. WATERS CURRENTLY USED FOR THEIR MINERAL CONTENT ARE BRINES (35,000 PPM DISSOLVED SOLIDS), BUT IMPROVED TECHNOLOGY SHOULD FACILITATE THE EXPLOITATION OF SALINE WATERS OF LOWER CONCENTRATIONS. BECAUSE HOT WATER IS A MORE EFFECTIVE SOLID THAN COLD WATER AND HAS HIGHER SATURATION LEVELS, SOME OF THE MOST CONCENTRATED BRINES ARE THERMAL WATERS. THE MINERAL CONSTITUENTS THAT COULD BE UTILIZED AND WHERE THEY MIGHT BE FOUND, ARE CONSIDERED. PARTICULAR ATTENTION IS PAID TO THE SALTON SEA GEOTHERMAL AREA AND TO THE PERMIAN BASIN OF SOUTHEASTERN NEW MEXICO. THE LACK OF DETAILED DATA COMBINED WITH INADEQUATE HYDROMETALLURGICAL PROCEDURES ARE PROBLEMS THAT WILL SOON BE OVERCOME. (SEE ALSO W72-01749) (CASEY-ARIZONA)

Mineral deposition from Icelandic geothermal waters: Environmental and utilization problems

Arnosson, S.

Univ. of Iceland

1979 SPE International Symposium on Oilfield and Geothermal Chemistry 791 2195 Houston, Texas 22-24 Jan 79

Society of Petroleum Engineers (American Institute of Mining, Metallurgical & Petroleum Engineers); American Society of Mechanical Engineers

Papers and abstracts (Eng) in bound volume, 22 Jan 79, \$20.00: C/O SPE, 6200 North Central Expressway, Dallas, TX 75206.

Possibilities for a geothermal energy & mineral industrial complex in Salton Sea area

Hornburg, C.D.

American Institute of Chemical Engineers 83rd National Meeting/9th Petrochemical and Refining Exposition A771035 Houston, Texas 20-24 Mar 77

American Institute of Chemical Engineers

Paper No: 16C.

Papers preprints in microfiche form; \$.65 per fiche, members; \$1, others. Request order blank from: AIChE, 345 E 47 St., New York, NY 10017. Paper copies (price n a) available from: Engineering Societies Library, 345 E 47 St., New York, NY 10017.

Rapid evolution of geothermal systems in new oceanic crust predicts mineral output mainly near ridge crests

Lister, C.R.

American Geophysical Union 1975 Fall Annual Meeting A754010 San Francisco, California 8-12 Dec 75

American Geophysical Union

Abstracts in -EOS", Dec 75; \$5: AGU, 1919 K Street, N.W., Washington, D.C. 20006, USA. Post-deadline and revised abstracts in program. Inquire: AGU, address above. Conference report in -EOS", early 76; \$5: AGU, address above.

SEAWATER DESALINATION BY REVERSE-OSMOSIS (ENGLISH)

POHLAND HW

DUPONT CO/WILMINGTON//DE/19898

ENDEAVOUR, V4, N4, P141-147, 1980

LOW-TEMPERATURES AND DISSOLVED-GASES - 2 PROBLEMS IN SUBMARINE SEA-WATER DESALINATION (ENGLISH)

HAMPE M

TECH UNIV MUNICH, DEPT CHEM ENGN/D-8000 MUNICH 2//FED REP GER/

DESALINATION, V34, N1-2, P35-56, 1980

A SCHEME FOR LARGE-SCALE DESALINATION OF SEA-WATER BY SOLAR-ENERGY (ENGLISH)

RAJIVANSHI AK

UNIV FLORIDA, SOLAR ENERGY & ENERGY CONVERS LAB/GAINESVILLE//FL/32611

SOLAR ENERGY, V24, N6, P551-560, 1980

INVESTIGATION OF HEAT-EXCHANGE DURING SEA-WATER BOILING IN A HORIZONTAL THIN-FILM DESALINATION PLANT (ENGLISH)

SLESARENKO V

FAR EASTERN POLYTECH INST/VLADIVOSTOK//USSR/ DESALINATION, V29, N3, P311-318, 1979

TOTAL DESALINATION OF BRACKISH WATER (ENGLISH)

RAUTENBACH R; HENNE KH

INST VERFAHRENTSCH, TURMSTR 56/D-5100 AACHEN//FED REP GER/ DESALINATION, V30, N1-3, P581-581, 1979

OPTIMIZATION OF A DUAL PURPOSE PLANT FOR SEAWATER DESALINATION AND ELECTRICITY PRODUCTION (ENGLISH)

KUENSTLE K; JANISCH V

KRAFTWERK UNION/ERLANGEN//FED REP GER/ DESALINATION, V30, N1-3, P555-569, 1979

DESALINATION OF SEA-WATER - ENERGY SAVING SOLUTION, VAPOR COMPRESSION (FRENCH)

BLANCFERAUD P
ELECT FRANCE, DIRECT ETUDES & RECH, SERV ENSEMBLES PROD, 6 QUAI
WATIER/F-78400 CHATOU//FRANCE/
DESALINATION , V30, N1-3, P469-482, 1979

SEA-WATER DESALINATION BY REVERSE-OSMOSIS IN CHIGASAKI LABORATORY (ENGLISH)

KUNISADA Y; KANEDA H; HIRAI M; MURAYAMA Y
WATER REUSE PROMOT CTR, 2-3-4 AKASAKA, MINATO KU/TOKYO
107//JAPAN/
DESALINATION , V30, N1-3, P337-345, 1979

TEST CENTER FOR THERMAL SEAWATER DESALINATION PLANTS (ENGLISH)

HAPKE J; OSTERHOLT K
UNIV DORTMUND, CHEMIETECH ABT/D-4600 DORTMUND 50//FED REP
GER/; THYSSSEN ENGN GMBH/ESSEN//FED REP GER/
DESALINATION , V30, N1-3, P101-126, 1979

SEAWATER DESALINATION AND REVERSE-OSMOSIS PLANT-DESIGN (ENGLISH)

POHLAND HW
DUPONT CO, PERMASEP PROD/WILMINGTON//DE/19898
DESALINATION , V32, N1-3, P157-167, 1980

CONSIDERATIONS ON FILTRATION MECHANISM IN PRETREATMENT PROCESS OF SEA-WATER DESALINATION BY REVERSE-OSMOSIS (ENGLISH)

MATSUMURA T; FURUTA I; TAKEDA M; TSUGE H; SUGINO Y
KOBE STEEL LTD, MECH ENGN RES LAB, FUKIAI KU/KOBE//JAPAN/
DESALINATION , V32, N1-3, P93-101, 1980

SPIRAL-WOUND NEW THIN-FILM COMPOSITE MEMBRANE FOR A SINGLE-STAGE SEAWATER DESALINATION BY REVERSE-OSMOSIS (ENGLISH)

KURIHARA M; KANAMARU N; HARUMIYA N; YOSHIMURA K; HAGIWARA S
TORAY IND INC/OTSU/SHIGA 520/JAPAN/; TORAY RES CTR
LTD/OTSU/SHIGA 520/JAPAN/
DESALINATION , V32, N1-3, P13-23, 1980

VTE BOILER - ADVANCED THERMAL SYSTEM FOR THE DESALINATION OF SEA-WATER (ENGLISH)

KAMAL I; HUGHES CH
ENVIROGEN SYST CO/EL MONTE//CA/
DESALINATION , V31, N1-3, P533-544, 1979

CHEMISTRY OF ALKALINE SCALE INHIBITION IN SEAWATER DESALINATION BY FLOCON ANTISCALANT-247 (ENGLISH)

WALINSKY SW; MORTON BJ
PFIZER INC, CENT RES/GROTON//CT/06340
DESALINATION , V31, N1-3, P289-298, 1979

MSF-SEAWATER DESALINATION PLANTS USING WASTE HEAT FROM ELECTRIC-ARC FURNACES IN THE STEEL-INDUSTRY (ENGLISH)

RAUTENBACH R; MONHEIM P; ZEBROWSKI D
RHEIN WESTFAL TH AACHEN/D-5100 AACHEN//FED REP GER/;
MANNESMANN DEMAG/DUISBURG//FED REP GER/
DESALINATION , V31, N1-3, P197-206, 1979

ESSENTIALS ON SEA-WATER DESALINATION THROUGH VAPOR COMPRESSION (ENGLISH)

LARGER D
SOC INT DESSALEMENT EAU MER/PARIS//FRANCE/
DESALINATION , V31, N1-3, P131-134, 1979

DESALINATION OF SEAWATER BY VAPOR COMPRESSION (FRENCH)

LARGER D
SOC INT DESSALEMENT EAU MER/PARIS//FRANCE/
DESALINATION , V31, N1-3, P125-130, 1979

SINGLE-PURPOSE REACTOR FOR SEA-WATER DESALINATION (ENGLISH)

RONEN Y; HADARI Z; GLUECKSTERN P
BEN GURION UNIV NEGEV, DEPT NUCL ENGN/BEER SHEVA
84120//ISRAEL/; MEKOROTH WATER CO LTD/TEL AVIV//ISRAEL/
ATOMKERNENERGIE-KERNTECHNIK , V34, N2, P143-145, 1979

SELECTION OF MATERIALS AND CORROSION PROBLEMS IN SEA-WATER DESALINATION (GERMAN)

HIRSCHFELD D
FRIED KRUPP GMBH, INST FORSCH/ESSEN//FED REP GER/
TECHNISCHE MITTEILUNGEN KRUPP WERKSBERICHTE , V37, N2, P
55-66, 1979

INVESTIGATION ON SEA-WATER DESALINATION PLANTS IN SPAIN (ENGLISH)

MURO S; STERNER R; UGARTE J
JUNTA ENERGIA NUCL/MADRID//SPAIN/; BABCOCK & WILCOX
ESPANOLA/MADRID//SPAIN/
DESALINATION , V28, N2, P109-116, 1979

LONG-TERM EXPERIMENTS ON SEA-WATER DESALINATION AT THE CHIGASAKI LABORATORY (ENGLISH)

KUNISADA Y; MURAYAMA Y
WATER RE-USE PROMOT CTR/TOKYO//JAPAN/
DESALINATION , V27, N3, P333-344, 1978

WORLDS 1ST LARGE SEAWATER REVERSE-OSMOSIS DESALINATION PLANT, AT JEDDAH, KINGDOM OF SAUDI ARABIA (ENGLISH)

ALGHOLAIAH A; ELRAMLY N; JAMJOOM I; SEATON R
MINIST AGR & WATER, WATER AFFAIRS/RIYADH//SAUDI ARABIA/;
SALINE WATER CONVERS CORP, TECH & PROJECT AFFAIRS/JEDDAH//SAUDI
ARABIA/; UOP INC, DIV FLUID SYST/SAN DIEGO//CA/; UNIV
HAWAII/HONOLULU//HI/96822
DESALINATION , V27, N3, P215-231, 1978

SEA-WATER DESALINATION AND ITS ENERGY SUPPLY - VDI CONFERENCE, NOVEMBER 17, 1977, IN DUSSELDORF AND DECEMBER 12, 1977, IN COLOGNE (GE)

QUACK R
UNIV STUTTGART, INST VEFAHRENSTECH & DAMPFKESSELWESEN/D-7000
STUTTGART 80//FED REP GER/
BRENNSTOFF-WARME-KRAFT , V31, N1, P29-30, 1979

OPERATING EXPERIENCE IN BRACKISH WATER DESALINATION USING REVERSE-OSMOSIS (GERMAN)

WEISE A
FRIED KRUPP GMBH, KRUPP ATLAS MASCHINENBAU/BREMEN//FED REP
GER/
TECHNISCHE MITTEILUNGEN KRUPP WERKSBERICHTE , V36, N2, P
33-40, 1978

DESALINATION OF SEAWATER AND BRACKISH WATER BY HIGH-TEMPERATURE ELECTRODIALYSIS (GERMAN)

EGGERSDORFER R; HAMPEL HJ; KOHLING A; SCHERER KH
BATTELLE INST EV, POSTFACH 900160/D-6000 FRANKFURT 90//FED
REP GER/
CHEMIE INGENIEUR TECHNIK , V50, N5, P395-395, 1978

DESALINATION OF SEA-WATER THROUGH REVERSE-OSMOSIS (GERMAN)

BODDEKER KW
CHEMIKER-ZEITUNG , V102, N3, P103-103, 1978

SEAWATER DESALINATION BY ELECTRODIALYSIS (ENGLISH)

SETO T; EHARA L; KOMORI R; YAMAGUCHI A; MIWA T
ASAHI CHEM IND CO LTD/TOKYO//JAPAN/
DESALINATION , V25, N1, P1-7, 1978

STEAM-TURBINES AS SUPPLIERS OF HEAT FOR SEA-WATER DESALINATION PLANTS (ENGLISH)

SPECHTENHAUSER A
BROWN BOVERI REVIEW , V64, N9, P522-531, 1977

**SEA-WATER DESALINATION-DISTRICT HEATING - FOREWARD
(ENGLISH)**

DEHM A

BROWN BOVERI REVIEW , V64, N9, P512-512, 1977

**REVERSE-OSMOSIS PILOT PLANTS PERFORMANCE IN BRACKISH WATER
DESALINATION (ENGLISH)**

BOARI G; CARRIERI C; MAPPELLI P; SANTORI M

CNR,IST RICERCA ACQUE/ROMA//ITALY/

DESALINATION , V24, N1-3, P341-364, 1978

**DESALINATION OF BRACKISH WATER BY BUBBLE-CLEANING TYPE
ELECTRODIALYZER IN LARGE-SCALE (ENGLISH)**

KURODA O; MATSUZAKI H; TAKAHASHI S; SHIMOZATO A; KOIKE Y

HITACHI LTD,HITACHI RES LAB/HITACHI//JAPAN/; HITACHI PLANT
ENGN & CONSTRUCT CO LTD/TOKYO//JAPAN/; HITACHI LTD,DIV
ENVIRONM DISASTER PROTECT SYST ENGN/HITACHI//JAPAN/

DESALINATION , V22, N1-3, P515-524, 1977

**5,000,000 IMP GAL-DAY SEA-WATER DESALINATION PLANT FOR
MINISTRY-OF-ELECTRICITY-AND-WATER, GOVERNMENT-OF-KUWAIT (ENG-
LISH)**

HARASHINA H

ISHIKAWAJIMA HARIMA HEAVY IND CO LTD,DEPT PLANTS ENGN 2,DIV
CHEM PLANTS/TOKYO//JAPAN/

DESALINATION , V22, N1-3, P425-434, 1977

**FIELD EXPERIENCE OF SEAWATER DESALINATION BY REVERSE-OSMOSIS
SYSTEM, OPERATING IN SAUDI-ARABIA (ENGLISH)**

KIJIMA J; MIZUNIWA T; HAYAKAWA M; TANIGUCHI Y

KURITA WATER IND LTD/TOKYO//JAPAN/

DESALINATION , V22, N1-3, P299-309, 1977

**DEVELOPMENT OF SEAWATER DESALINATION BY REVERSE-OSMOSIS
PROCESS IN JAPAN (ENGLISH)**

KUNISADA Y; MURAYAMA Y; HIRAI M

DESALINATION , V22, N1-3, P243-252, 1977

**ECONOMIC EVALUATION OF USING SMALL SIZED NUCLEAR-REACTORS
FOR SEAWATER DESALINATION (ENGLISH)**

GLUECKSTERN P; KANTOR Y

MEKOROTH WATER CO LTD/TEL AVIV//ISRAEL/

DESALINATION , V22, N1-3, P101-110, 1977

**SPIRAL-WOUND THIN-FILM COMPOSITE MEMBRANE SYSTEMS FOR
BRACKISH AND SEAWATER DESALINATION BY REVERSE-OSMOSIS
(ENGLISH)**

RILEY RL; MILSTEAD CE; LLOYD AL; SEROY MW; TAGAMI M

UNIVERSAL OIL PROD INC,DIV FLUID SYST,DEPT BAS DEV/SAN
DIEGO//CA/92117

DESALINATION , V23, N1-3, P331-355, 1977

**DESALINATION OF SEA-WATER BY REVERSE-OSMOSIS USING TUBULAR
MODULE (ENGLISH)**

TSUGE H; YANAGI C; MORI K

KOBE STEEL LTD,MECH ENGN RES LAB,FUKIAI KU/KOBE//JAPAN/

DESALINATION , V23, N1-3, P235-243, 1977

**POLLUTION OF COASTAL SEA-WATER AND SULFATE REDUCING BACTERIA
IN CONNECTION WITH MICROBIAL CORROSION OF METALLIC MATERIALS
IN DESALINATION PLANTS (ENGLISH)**

NAKAHARA T; SASAKI H; KANDA Y; TOGANO H

NATL CHEM LAB IND/TOKYO//JAPAN/

DESALINATION , V23, N1-3, P151-160, 1977

SEAWATER DESALINATION AND ITS ENERGY SUPPLY (GE)

QUACK R

INST VERFAHRENSTECH & DAMPFKESSELWESEN/D-7000 STUTTGART
80//FED REP GER/

CHEMIE INGENIEUR TECHNIK, V49, N11, P918-921, 1977

**HYDRODYNAMICS AND HEAT-TRANSFER DURING SEAWATER BOILING IN
THIN-FILM DESALINATION PLANTS (EN)**

SLESARENKO V

FAR EASTERN POLYTECH INST/VLADIVOSTOK//USSR/

DESALINATION, V21, N3, P275-283, 1977

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ANNALS OF NUCLEAR ENERGY, V4, N4-5, P183-184, 1977

DESALINATION OF SEA-WATER (EN)

MORRIS RM
WEIR WESTGARTH LTD/GLASGOW G44 4EX//SCOTLAND/
CHEMISTRY AND INDUSTRY, V1977, N15, P653-658, 1977

5TH INTERNATIONAL-SYMPOSIUM ON DESALINATION OF SEA AND SALT-WATER (EN)

MARTYNOVA OI
SOVIET ATOMIC ENERGY, V41, N4, P933-933, 1976

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CHIMICA E L INDUSTRIA, V59, N4, P291-293, 1977

FRESH-WATER FROM SALINE WATER - SEA-WATER AND BRACKISH WATER DESALINATION (GE)

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UMSCHAU IN WISSENSCHAFT UND TECHNIK, V77, N9, P267-273, 1977

ELECTROCHEMICAL BEHAVIOR OF ALUMINUM-ALLOYS IN CONNECTION WITH OPERATING-CONDITIONS OF A SEAWATER THERMAL DESALINATION PLANT (EN)

ALIEV AF; FREIMAN LI
ALL UNION WATER SUPPLY,SEWER SYST HYDRAUL ENGN STRUCT & ENGN HYDROGEOL INST/BAKU//AZSSR/
PROT MET R, V12, N4, P351-356, 1976

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CHANNABASAPPA KC
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DESALINATION, V19, N1-3, P535-554, 1976

DESIGN OF REVERSE-OSMOSIS SYSTEMS FOR COMMERCIAL SEAWATER DESALINATION (EN)

BULLOCK DC
POLYMETRICS INC/SANTA CLARA//CA/95052
DESALINATION, V19, N1-3, P397-404, 1976

DEUTERIUM ENRICHED BRINE AS A BY-PRODUCT FROM DESALINATION PLANTS (EN)

VALFELLS A
IOWA STATE UNIV,ENGN RES INST,DEPT CHEM ENGN & NUCL ENGN/AMES//IA/50011; UNIV ICELAND,INST SCI/REYKJAVIK//ICELAND/DESALINATION, V19, N1-3, P55-64, 1976

THERMODYNAMIC ANALYSIS OF RE-GASIFICATION OF LNG FOR DESALINATION OF SEA-WATER (EN)

CRVALHO EG; MCGRATH JJ; TOSCANO WM
MIT,DEPT MECH ENGN/CAMBRIDGE//MA/O2139; CTI CRYOGEN/WALTHAM-//MA/O2154
CRYOGENICS, V17, N3, P135-139, 1977

PRACTICAL ASPECTS OF SEA-WATER DESALINATION BY REVERSE-OSMOSIS (EN)

SALTONSTALL CW
ENVIROGEN SYST CO/EL MONTE//CA/
DESALINATION, V18, N3, P315-320, 1976

REVERSE OSMOSIS THEORY OF PERMEATION AND APPLICATION TO SEAWATER DESALINATION (JA)

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DENKI KAGAKU, V44, N4, P248-254, 1976

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FERNANDEZSANCHEZ M; UGARTEGUTIERREZ J
JUNTA ENERGIA NUCL,DIV INGN NUCL/MADRID//SPAIN/; JUNTA ENERGIA NUCL,DIV INGN NUCL/MADRID//SPAIN/
ENERGIA NUCLEAR, V20, N101, P185-191, 1976

SEAWATER DESALINATION BY REVERSE-OSMOSIS (EN)

ROSENBLATT NW
DU PONT CO/WILMINGTON//DE/19898
ACS SYMPOSIUM SERIES, V1975, N18, P519-548, 1975

DESALINATION OF SEA-WATER USING SOLAR-RADIATION UNDER RETARDED EVAPORATION CONDITIONS (EN)

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ILLINOIS INST TECHNOL,DEPT CHEM ENGN/CHICAGO//IL/60616
INDUSTRIAL AND ENGINEERING CHEMISTRY PROCESS DESIGN & DEVELOPMENT, V14, N4, P351-358, 1975

ENCrustATION AND ITS SUPPRESSION IN THERMAL DESALINATION OF SEAWATER BY TREATMENT OF SEAWATER FEED (GE)

PANAHANDAH H
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CHEMIE INGENIEUR TECHNIK, V47, N16, P664-670, 1975

DESALINATION OF SEA-WATER BY DIRECT OSMOSIS (EN)

KRAVATH RE; DAVIS JA
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PEDIAT/BRONX//NY/10467
DESALINATION, V16, N2, P151-155, 1975

EFFECTS OF DESALINATION BRINES ON CRASSOSTREA-VIRGINICA (GMELIN) (EN)

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WATER RESEARCH, V9, N3, P287-295, 1975

SEAWATER DESALINATION BY REVERSE-OSMOSIS (EN)

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ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY, V1975,
N169, P36-36, 1975

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UNIV CALIF, DEPT CHEM ENGN/RICHMOND//CA/94804; UNIV
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DESALINATION, V16, N1, P39-53, 1975

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CASU D; MARTINO V; PUXEDDU C
SIR SPA, LAB COMPLESSO/PORTO TORRES//ITALY/
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CHEMIE INGENIEUR TECHNIK, V46, N11, P485-485, 1974

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SYSTEMS-ANALYSIS OF A MULTISTAGE TUBULAR MODULE REVERSE-OSMOSIS PLANT FOR SEA-WATER DESALINATION (EN)

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**SEA-WATER DESALINATION USING GLASS HOLLOW FIBER MEMBRANES
(EN)**

PHILLIPS SV; CROZIER DS; MCMILLAN PW; TAYLOR JMC
GE CO LTD/STAFFORD//ENGLAND//; HM DOCKYARD/PORTSMOUTH//ENGLA-
ND/
DESALINATION, V14, N2, P209-216, 1974

**SYSTEMS-ANALYSIS OF A MULTISTAGE TUBULAR MODULE
REVERSE-OSMOSIS PLANT FOR SEA-WATER DESALINATION (EN)**

MCCUTCHA JW; GOEL V
UNIV CALIF, SCH ENG & APPL SCI, ENERGY & KINETICS DEPT/LOS
ANGELES//CA/90041
DESALINATION, V14, N1, P57-76, 1974

**SEA-WATER DESALINATION BY REVERSE-OSMOSIS RECENT EXPERIENCE
(EN)**

TREILLE P; ROVEL JM
SOC DEGREMONT/SURESNES//FRANCE/
DESALINATION, V14, N1, P21-31, 1974

**METHOD FOR REMOVAL OF INCRUSTED SALTS IN VAPORIZER
APPARATUSES FOR SEA-WATER DESALINATION (GE)**

GENTHER K; STEPHAN K; KRIEDEL E; SCHREIBER H
BRENNSTOFF-WARME-KRAFT, V26, N2, P77-77, 1974

0072171 MEETING AB OATS ORDER#: S2050 0 REFS

**SEA-WATER CIRCULATING PLANT FOR CORROSION TESTS ON MATERIALS
FOR SEA-WATER DESALINATION PLANTS - FIRST EXPERIENCES (GE)**

FROHNER KR
GESELL KERNENERGIEVERWERTUNG SCHIFFBAU & SCHIFFFAHRT
MBH/GEESTHACHT//WEST GERMANY/
CHEMIE INGENIEUR TECHNIK, V46, N4, P168-169, 1974

GEOBRINE MINERALS RECOVERY

INVESTIGATORS: Schultze LE; Bauer DJ; Lindstrom RE
PERFORMING ORG: U.S. Dept. of the Interior, Bureau of
Mines, Reno Research Center, Reno, Nevada, 89520, United States of
America

SPONSORING ORG: U.S. Dept. of the Interior, Bureau of
Mines, Reno Research Center, Reno, Nevada, 89520, United States of
America

CONTRACT/GRANT NO.: D-4-I; 9449-8
10/76 TO 0/81 FY: 80 FUNDS: \$100,000

PURPOSE: To research and demonstrate extraction technology
for the economic recovery of minerals and metals from
geobrine. Methods for recovering minerals and metals such as
manganese, lithium zinc, iron, and lead, from geobrine will
be developed. Liaison will be maintained with geothermal
operations in the western states.

DEVELOPMENT OF NEW CHEMICAL ADDITIVES AND TREATMENTS FOR SCALE CONTROL IN SALINE WATER EVAPORATORS

INVESTIGATORS: Miller

PERFORMING ORG: Battelle Memorial Inst., 505 King
Ave., Columbus, Ohio, 43201, United States of America

SPONSORING ORG: U.S. Dept. of the Interior, Office of Water
Research & Technology, 18th & C Sts. N.W., Washington, District
of Columbia, 20240, United States of America

CONTRACT/GRANT NO.: C-001605-OHIO
0/80 TO 10/81 FY: 80 FUNDS: \$126,018

No summary has been provided to the Smithsonian Science
Information Exchange.

SIDESTREAM TREATMENT OF HIGH SILICA COOLING WATER AND REVERSE OSMOSIS DESALINATION FOR REUSE IN GEOTHERMAL POWER GENERATION

INVESTIGATORS: Mindler AB

PERFORMING ORG: Permutit Co. Inc., 567 Ridge Rd., Monmouth
Junction, New Jersey, 08852, United States of America

SPONSORING ORG: U.S. Dept. of the Interior, Office of Water
Research & Technology, 18th & C Sts. N.W., Washington, District
of Columbia, 20240, United States of America

CONTRACT/GRANT NO.: 14-34-0001-9527
9/79 TO 9/80 FY: 80 FUNDS: \$107,000

The objective of this study is to develop a method for
silica removal with minimum increase in pH in sidestream
treatment. The approach used is to employ adsorption of SiO₂
on ferric oxide produced by accelerated rusting of iron
turnings available as short shovel shavings. Pilot plant work
will be performed at DOE geothermal energy recovery complex on
warm recirculating water going to cooling tower operating at
5x concentration cycles with make-up of 3000 ppm total
dissolved solids and 20 to 30 ppm silica. Make-up water and
desilicized water will be ion exchange softened with
regeneration by reject brine from RO desalination. Blowdown
water reuse by RO for control of dissolved salts will be
studied with product water used for potable supply and reject
for regeneration of softeners. Potable permeate will be
treated for fluoride removal by adsorption on alumina.
Chromate recovery will be by adsorption on anion exchange
resin for reuse as corrosion inhibitor. Corrosion data on
carbon steel and alloys will be obtained.

ELECTROLYTE THERMODYNAMIC DATA

INVESTIGATORS: Staples BR

PERFORMING ORG: U.S. Dept. of Commerce, National Bureau of
Standards, Washington, District of Columbia, 20228, United States
of America

SPONSORING ORG: U.S. Dept. of Commerce, National Bureau of
Standards, Washington, District of Columbia, 20228, United States
of America

CONTRACT/GRANT NO.: 3165156
20228

10/76 TO 12/99 FY: 78 FUNDS: \$82,000

PRIOR YEAR ACCOMPLISHMENTS: Assessment of energy related
invention and tests of accuracy of solution thermodynamics
data, leading to proof of comparability of enthalpies of
dilution based on the first and second laws of thermodynamics.

IDENTIFIERS: Prior Funding: FY77 \$ 80,000

PROJECT OBJECTIVE: Provide engineers and scientists with
standard references data on thermodynamic properties of
electrolyte solutions. These data are required in the
analysis of problems in water quality control, geothermal
energy production, corrosion, sewage treatment desalination,
industrial processes and in the interpretation of chemical,
biochemical and geochemical systems.

PROJECT APPROACH: Prepare and publish evaluated data on the
osmotic and activity coefficients of electrolytes in water and
in selected thermodynamic properties of important constituents
on natural water systems. Develop and test methods for
evaluating data. Provide information services.

Utilization of highly mineralized mine drainage waters.

SANIN M. V.; KAMINSKII V. S.; TIMOSHINA I. A.

ACADEMY OF SCIENCES OF USSR

Water Resources (U.S.S.R.) 1979, 6, No.2, 280-287.

Languages: ENGLISH

Geographic Location: FRANCE; UKRAINE; RUSSIA; SAUDI ARABIA; U.S.S.R.

The options for greater use of the mineralized or saline and brackish waters resulting from mining operations in regions of the U.S.S.R. where water is not plentiful, e.g. in the Ukraine, are considered. Among the uses described are neutralization of acid mine wastes, irrigation of salt tolerant crops, recycling in closed systems to prevent pollution by discharge into surface waters, demineralization of waste waters from mining and utilization of the resulting brines by industrial reverse osmosis. Most of the experience quoted with these techniques is Russian, except for that relating to reverse osmosis which cites French expertise in Saudi Arabia.

Water pollution - groundwater.

BRAIDS O. C.; GILLIES N. P.

GERAGHTY & MILLER INC.

Journal of Water Pollution Control Federation (U.S.A.) 1979, Literature Review, 1471-1477.

Languages: ENGLISH

Geographic Location: AMERICA; UNITED STATES OF AMERICA; ILLINOIS

The protection of groundwater resources from contamination by seepage from landfill and waste disposal sites, irrigation of sewage and sewage stabilization ponds has been studied by numerous authors and known cases of contamination in the U.S.A. have been documented. Various schemes for the development of groundwater sources in North America have also been evaluated, and the use of groundwater reservoirs to compensate for water shortages due to climatic variations on an international scale has been proposed. The use of geothermal brines as a source of heat and, following desalination for augmenting water supplies has also been assessed in economic terms; a decrease in capital costs is needed for such systems to become competitive. Excessive levels of radioactivity have also been reported from wells in Illinois. 43 ref.

FERNICUS W. A.; COCCIER, M. K.
BUREAU OF RECLAMATION, BOULDER CITY
Journal of Environmental Engineering Division, ASCE
(U.S.A.) 1979, 105, No. EE1, 13-32.
Languages: ENGLISH
Geographic Location: EAST MESA; EAST MESA GEOTHERMAL TEST SITE

Test programmes at the East Mesa, Calif. geothermal test site are described, with details of the hydraulic characteristics and chemical composition of the brines obtained from a number of wells. Temperatures ranged from 150 to 200°C for different wells, and chloride levels from 500 to 15,850 mg per litre. Details of the operation and problems encountered with the use of artificial recharge wells and in the performance of a number of desalination units are given, comprising vertical tube evaporators, multi-stage flash distillation plants and high-temperature electrodialysis units.

Institutional approach toward combined industrial waste treatment.

BISHOP W. J.; BORGERDING J.; CALKINS R. J.
VENTURA REGIONAL COUNTY SANITATION DISTRICT
Journal of Water Pollution Control Federation (U.S.A.)
1979, 51, No.3, 612-618.
Languages: ENGLISH
Geographic Location: VENTURA COUNTY, CALIF.

The authors summarize studies to develop a regional facility for Ventura County, Calif., to treat residual industrial wastes (such as sludges and by products produced by preliminary treatment of industrial waste waters prior to discharge to the sewers). These may be categorized as oily wastes, brines, heavy metals wastes, non-metallic toxic wastes, and organic wastes. Flow diagrams of the treatment processes proposed for each type of waste are given, and costs of constructing the treatment plant are estimated.

The production of water from geothermal reservoirs: some economic considerations.

VAUX H. J.
Water Resources Bulletin 1977, 13, No.3, 469-478.
Languages: ENGLISH
There is increasing interest in the possible use of geothermal sources as a source of energy in the future, and the author suggests that such systems might also be used as a source of water supply, by desalination of the geothermal brines. However, the costs of production are probably too high, except for certain unique situations.

Saline ground waters produced with oil and gas.

COLLINS A. G.
EPA 660/2-74-010, Washington, D.C. 1974. 76 pp.
Languages: ENGLISH
More than 60,000 analyses of saline waters have been carried out by the U.S. Bureau of Mines, and entered in an automatic data processing system. The results of the analyses are used in studies on the source of a brine, classification of ground water, determination of sources of brine pollution, and feasibility of desalination of saline water; examples of each type of study are included.

Processes for industrial water clean-up.

LEITZ F. B.
Env. Sci. & Tech; 1976, 10, No. 2, 136-139.
Languages: ENGLISH
The author outlines the development of the electrodialysis process, describes the design of equipment, and gives some examples of typical applications of this process, including demineralization of brackish water, desalination of whey, and treatment of various waste waters containing ionic material, such as those from cellulose manufacture, metal works, glass etching, and various saline waste waters.

Desalination of brackish water by thermally regenerable ion exchange.

BATTAERD H. A. J.
Effl. Wat. Treat. J. 1974, 14, No. 5, 245-251.
Languages: ENGLISH
The 'Sirotherm' process used a mixed bed of newly-developed ion-exchange resins which are regenerated by hot water rather than chemicals. The process is said to be operable in standard ion-exchange equipment and pilot-scale tests indicate that it is economically competitive for waters containing up to 3000 mg of total dissolved solids per litre.

Mineral brines and their utilization through small-scale mining in the USA

Future of small scale mining
Collins, A.G.; Meyer, R.F.; Carman, J.S. (eds.)
Bartlesville Energy Research Center, Bartlesville, OK
151-156 p. 1978
1. International conference on the future of small-scale mining. Queretaro, Mexico. 27 Nov 1978
Country of Publication: United States
Publ: McGraw Hill, New York, NY.
Journal Announcement: EDB8109
Document Type: Analytic of a Book; Conference Literature
Languages: English
Subfile: TIC (Technical Information Center)
Report No.: CONF 7811184-
Work Location: United States
Extraction of minerals from oilfield and geothermal brines is considered. Mineral recovery methods, a preliminary economic evaluation, and the locations of valuable brines are discussed. (MHR).

Extraction of nonferrous metals from high salinity brine--geothermal brine by sulfide precipitation

Society of Mining Engineers of AIME, preprints, for presentation at AIME annual meeting, 1980

Bartlett, R.W.; Macdonald, D.D.; Farley, E.P.

Stanford Res Inst Int, Menlo Park, Calif

vp p. 1980

American Institute of Metallurgical Engineers meeting Las Vegas, NV, USA Feb 1980

Country of Publication: United States

Publ: Society of Mining Engineers of AIME, Littleton, CO.

Journal Announcement: EDB8104

Document Type: Analytic of a Book; Conference literature

Languages: English

Subfile: FI (COMPENDEX)

Report No.: CONF-800205-

Work Location: United States

High salinity geothermal brines typically contain up to several hundred parts per million of valuable heavy metals, and because of the large potential flow of geothermal brines from future power plants, metal production as a byproduct could be significant. The goal of computer simulation was to define the conditions required for selective precipitation of lead, zinc, and silver solid phases from brines that contain dissolved iron and manganese. 3 refs..

625878 ERA 05-023991, EDB-80:065402

Improvements in geothermal electric power and silica production (Patent)

Hill, J.H.; Fulk, M.M.

Patent No.: US Application 018,198

22 p. (nd)

Country of Publication: United States

Journal Announcement: EDB8006

Availability: NTIS, PC A02/MF A01.

Document Type: Patent

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Work Location: United States

Contract No.: W-7405-ENG-48

Electricity is generated from hot geothermal solution by extracting heat therefrom. Mineral solids which form in a so cooled geothermal solution are separated to recover minerals and facilitate reinjection of the solution into the ground. The separated solids are treated to recover silica by addition of an acid (amorphous silica precipitates) or a base (other minerals precipitate and soluble silicates are formed which are subsequently precipitated by acid neutralization). If desired, after silica is separated, other minerals can be separated and recovered..

Possibilities for a geothermal energy and mineral industrial complex in the Salton Sea area

Third geopressured geothermal energy conference

Hornburg, C.D.; Meriwether, J.

US Engineers, Inc., Ft. Lauderdale, FL

EC-25-FC-49 p. 1977

3. geopressured geothermal energy conference Lafayette, LA, USA 16 Nov 1977

Country of Publication: United States

Journal Announcement: EDB7905

Document Type: Analytic of a Report; Conference literature

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Report No.: CONF-771153-P2

Work Location: United States

The overall development of the Salton Sea KGRA by developing industrial complexes is discussed. These would make maximum utilization of the total resource by on-site utilization of extracted energy and minerals; and upgrading these minerals via industrial processes to higher value products. A typical analysis of Salton Sea brine and an estimation of amounts and values of some materials that may be extracted from Salton Sea brines are presented. (MHR).

Geothermal energy utilization (Book)

Wahl, F.F.

309 p. 1977

Country of Publication: United States

Publ: John Wiley and Sons, Inc., New York, NY.

Journal Announcement: EDB7903

Availability: \$18.95

Document Type: Book

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Work Location: United States

Discussion is presented under the following chapter titles: description of geothermal energy; geothermal brines and their chemical and physical properties; chemistry of carbonates as related to geothermal brine utilization; chemistry of silica as related to geothermal brine utilization; scale deposition; mechanical or electrical work from a thermal source; expansion

Performance of steam scrubbers at San Diego Gas and Electric Company's Geothermal Test Facility, Niland, California

Energy and mineral resource recovery

Holt, B.; Hutchinson, A.J.L.

Ben Holt Co., Pasadena, CA

233 245 p. 1977

American Nuclear Society topical meeting on energy and mineral recovery research Golden, CO, USA 12 Apr 1977

Country of Publication: United States

Journal Announcement: EDB7807

Document Type: Analytic of a Report; Conference literature

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Report No.: CONF-770440-

Work Location: United States

Geothermal brine contained in the Salton Sea KGRA near Niland, California is being processed in the Geothermal Loop Experimental Facility (GLEF) operated by San Diego Gas and Electric Company (SDG and E) and funded jointly by SDG and E and ERDA. Operational results of this facility are presented. The brine contains about 20 percent by weight of dissolved salts and up to three percent by weight of noncondensable gases, principally CO₂. The high noncondensable content of the geothermal fluid dictates using a binary cycle design. Fouling of heat exchange surfaces is avoided by flashing the two-phase well flow at four successively lower pressure stages and heating the working fluid with clean steam flashed from each stage. The steam contains considerable entrained salts, often over 1,000 ppm. These salts will in time scale up the heat exchanger tubes. Washing of the steam in a scrubber containing recirculating trays removes the entrained materials to 10 to 20 ppm. The trays have a low pressure drop (less than 2" water/tray) and require a low water rate. The enthalpy and energy losses are less than with other known types of steam purifiers. A description of the scrubber is presented, together with recent performance data at the GLEF.

Kinetics of reactions in geothermal fluids

Energy and mineral resource recovery

Downs, W.F.; Rimstidt, J.D.; Solomon, G.C.; Barnes, H.L.

Pennsylvania State Univ., University Park

246 249 p. 1977

American Nuclear Society topical meeting on energy and mineral recovery research Golden, CO, USA 12 Apr 1977

Country of Publication: United States

Journal Announcement: EDB7807

Document Type: Analytic of a Report; Conference literature

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Report No.: CONF-770440-

Work Location: United States

In order to evaluate the kinetics of hydrothermal alteration reactions, a series of medium temperature (350/sup O/C), medium pressure (300 bar) systems to circulate hydrothermal fluids through rock samples was constructed. Two rock types, granite gneiss and biotite adamellite, were reacted at a series of temperatures with both air-saturated, distilled water, and 0.1 m sodium chloride brine. A series of experiments was also run using pure quartz sand and distilled water. By combining the quartz data with that obtained from the more complex rock-leaching experiments, the dominant rate-controlling reactions can be determined. Sodium chloride, in solution, not only enhances the rate and extent of oxygen isotopic exchange but also changes the dominant feldspar-fluid reaction from the incongruent dissolution of feldspar. Proton-alkali ion exchange appears to be unimportant, but first order rates are found for SiO₂ dissolution, for Na-K exchange and for Ca dissolution/exchange from plagioclase. A comparison of the predicted and observed rates of increase of silica in solution indicates that less than 10 percent comes from the dissolution of quartz. The granitic gneiss, LA-6, consists of two feldspars, (plagioclase An/sub 10/; alkali feldspar-K/sup +/-/sub 90/), quartz, and less than 5 percent mafic minerals-chlorite, epidote and sulfides. Rock type LA-11, biotite adamellite, also contains two feldspars (plagioclase An/sub 30/; alkali feldspar-K/sup +/-/sub 95/), quartz but approximately 17 percent mafic minerals-biotite, 12 percent hornblende, epidote, sphene and sulfides, 5 percent. Preliminary calculations indicate that the alteration of biotite to vermiculite is a rate controlling reaction for the addition of K/sup +/-/ to water-dominant hydrothermal solutions. Alkali ion exchange between solution and feldspar at least partially buffers the solution composition when brines are involved.

Effect of temperature and stress on the absolute permeability of sandstones and limestones

Energy and mineral resource recovery

Arana, M.; Aribara, N.; Ramey, H.D. Jr.

Stanford Univ., CA

541-550 p. 1977

American Nuclear Society topical meeting on energy and mineral recovery research Golden, CO, USA 12 Apr 1977

Country of Publication: United States

Journal Announcement: EDB7807

Document Type: Analytic of a Report; Conference literature

Languages: English

Subfile: ERA ((Energy Research Abstracts)); TIC ((Technical Information Center))

Report No.: CONF-770440-

Work Location: United States

Experiments by Weinbrandt (1972) indicated that the absolute permeability to water for consolidated sandstones decreased markedly with an increase in either confining pressure or the system temperature. Recent experiments by Casse (1974) showed that a large decrease in absolute permeability with temperature increase was peculiar to flow of water in the several consolidated sandstones studied. These experiments were repeated in the present study for other sandstones, and no strong effect was observed for flow of gas, mineral oil, or octanol. Under the hypothesis that a temperature level effect was caused by an attraction between water and quartz which increased with temperature increase, experiments were conducted with flow of water in both consolidated and unconsolidated sandstones. A large, reversible reduction in absolute permeability to water with temperature increase was observed, while no temperature level effect was observed for flow of gas or other non-aqueous fluids. Several experiments with flow of water through limestone samples were conducted. No temperature level effect was observed. It appears that temperature level may affect permeability to water in sandstone systems to an important degree. This should have important connotations to thermal oil recovery and geothermal fluid production.

Removal of hydrogen sulfide from simulated geothermal brines by reaction with oxygen

Energy and mineral resource recovery

King, J.E.; Wilson, J.S.

Dow Chemical U.S.A., Freeport, TX

221-232 p. 1977

American Nuclear Society topical meeting on energy and mineral recovery research Golden, CO, USA 12 Apr 1977

Country of Publication: United States

Journal Announcement: EDB7807

Document Type: Analytic of a Report; Conference literature

Languages: English

Subfile: CRA ((Energy Research Abstracts)); TIC ((Technical Information Center))

Report No.: CONF-770440-

Work Location: United States

The approach taken was to prepare simulated geothermal waters and test the oxidative process over a range of temperatures. The oxygen was injected in controlled quantities into a flowing stream of the hot brine. A reaction zone with a five-minute residence time was provided, with sampling points at one minute intervals to follow the course of the reaction. Corrosivity of the water was measured before and after the oxygen injection. The hot brine stream was disposed of through a 2-flash, 2-condenser system to reduce the temperature of the liquid being released to less than 100/sup o/C. Four principal tasks were carried out. These are as follows: (1) Determination of optimum oxygen-sulfide mole ratio to most effectively remove the hydrogen sulfide while still avoiding the presence of excess oxygen and the resulting extreme corrosivity. (2) Establish the temperature dependence of the reaction and estimate completion time at various temperatures and optimum oxygen-sulfide ratio. (3) Examine effects of dissolved solids content upon the rate of reaction with special emphasis on possible catalytic properties of heavy metal ions which are present in trace quantities in most geothermal fluids. (4) Determine the effects of variables such as pH and the presence of ammonia and/or the presence of sulfate ions on the reaction. Results indicate that the injection of oxygen appears to be a viable method of eliminating the hydrogen sulfide problem in geothermal waters.

Hydrogen sulfide removal from geothermal steam

Energy and mineral resource recovery

Brown, F.C.; Harvey, W.W.; Warren, R.B.

ETC Corp., Newton, MA

89-101 p. 1977

American Nuclear Society topical meeting on energy and mineral recovery research. Golden, CO, USA 12 Apr 1977

Country of Publication: United States

Journal Announcement: EDB7807

Document Type: Analytic of a Report; Conference Literature

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Report No.: CONF-770440

Work Location: United States

The process described entails the removal of hydrogen sulfide from geothermal steam by precipitation in advance of the turbine generator. For the purpose, a scrubber column is employed with a recirculating countercurrent flow of dilute copper sulfate solution. Laboratory (to 200 lb/hr steam flow) and field (1000 lb/hr) trials showed that hydrogen sulfide is removable at a steam-phase mass transport limited rate and that hydraulic conditions in the column can be adjusted to achieve over 90 percent removal. Significant removals of ammonia and boric acid occurred as well, with negligible degradation of steam quality. The copper sulfide precipitate consisted of tight aggregates of fine ultimate particle size and settled rapidly. Its reactivity toward oxidation makes possible its quantitative reconversion to copper sulfate by a mild pressure leach. In addition to scrubbing, liquid/solid separation and regeneration, results of corrosion and materials testing are described. Information is included on the successful outcome of a recent field test at the Geysers, and the process engineering and design for a larger geothermal steam scrubber is outlined.

Pollution control in geothermal energy

Proceedings of the 12th intersociety energy conversion engineering conference. Vol. I

Hartley, R.P.

Environmental Protection Agency, Cincinnati

607-613 p. 1977

12. intersociety energy conversion engineering conference. Washington, DC, USA 28 Aug 1977

Country of Publication: United States

Publ: American Nuclear Society, Inc., La Grange Park, IL

Journal Announcement: EDB7804

Note: See CONF-770804--P1

Document Type: Analytic of a Book; Conference Literature

Languages: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Work Location: United States

Pollution problems will occur in geothermal energy development because large volumes of spent geothermal fluid will be released, potentially contaminating the air, surface waters, and ground waters. Waters may be highly saline and contain metals in hazardous concentrations. Noncondensable gases are of greatest concern in air discharges. The principal anticipated liquid disposal method is reinjection to the producing reservoir, for which reliable technologies must be developed. Water treatment for surface discharge could be possible but costly, although minerals recovery might be offsetting in some cases. The principal air pollutant of concern is hydrogen sulfide although such constituents as ammonia, radon, and mercury may also be significant. Considerable development and demonstration is under way for hydrogen sulfide removal. Resource characterization data are not yet sufficient to predict the full range of potential pollution problems, particularly for the widespread and variable liquid-dominated resource.

Geothermal development of the Salton Sea

Hornburg, G.D.

BSS Eng. Inc., Fort Lauderdale, Fla

Chem. Eng. Prog. (United States) 73:7 89-94 p. Jul 1977 Coden: CEPRA

Journal Announcement: EDB7801

Document Type: Journal Article

Language: English

Subfile: EI (COMPIINDEX)

Work Location: United States

This paper reports results of a study which shows that the overall development of the geothermal resource of the Salton sea KGRA can best be done by developing industrial complexes. These would make maximum utilization of the total resource by on-site utilization of extracted energy and minerals; and upgrading these materials via industrial processes to higher value products. The key to these synergistic production facilities lies with economical recovery of the basic components in the brines. Thus, once the overall complex scheme has been established and shown to be technically feasible and economically attractive, emphasis should be placed on the technical problems and processes for basic mineral extraction. 16 refs..

History of exploitation at Salton Sea Geothermal Field, California

Howard, J.H.; Towse, D.

Univ. of California, Livermore

Am. Assoc. Pet. Geol. Bull. (United States) 61:5 796 p. May 1977 Coden: AAPGB

AAPG-SEPM annual convention Washington, DC. USA 12 Jun 1977

Journal Announcement: EDB7710

Document Type: Journal Article; Conference Literature

Language: English

Subfile: ERA (Energy Research Abstracts); TIC (Technical Information Center)

Work Location: United States

Geologically and historically, the Salton Sea Geothermal Field is among the most interesting in the world. Structure of the field reflects the interaction of the East Pacific Rise and the North American plate and includes a series of active northwest-trending strike-slip faults. The stratigraphic section includes a series of lacustrine and braided-stream deposits of the ancestral Colorado River. The reservoir is liquid dominated. Temperatures as high as 630/sup O/F (332/sup O/C) have been reported. Porosities are as much as 30 percent at shallow depths but decrease rapidly with increasing depth and temperature. Fractures are an important factor in flow. Permeabilities lie in the range of a few hundred millidarcys. Estimates of the electric-energy potential range from 80 to 800 megawatt-centuries. Attempts at energy recovery began in 1927; in addition, considerable effort has been devoted to minerals recovery. Carbon dioxide for refrigeration was taken from the field from 1932 to 1954. During the early 1960s, a serious but unsuccessful effort was made to recover other minerals, including potassium chloride. Attempts to exploit the energy from this resource continue today. ERDA, San Diego Gas and Electric Co., and Imperial Magma Co. are evaluating a flashed stream-binary-exchange power-production system. In addition, Lawrence Livermore laboratory under contract to ERDA is evaluating still other innovative energy-recovery schemes, including the "total flow" system, which holds promise of greater efficiency of energy production. Interest in minerals recovery continues, but no major effort has been fielded in recent years..

1296 (UCID--18646) DEFLUORIDATION STUDY FOR
BOISE GEOTHERMAL WATER. Rigdon, L.
(California Univ., Livermore (USA). Lawrence
Livermore Lab.). 3 Jun 1980. Contract W-
7405-ENG-48. 25p. NTIS, PC A02/MF A01.

Methods of removing fluorides from water are reviewed and recommendations are made for treating geothermal water used by the Boise Geothermal Project, Boise, Idaho. The Boise geothermal water except for its high fluoride content would be high quality, suitable for primary drinking water. Fluoride ranges from about 15 to 25 mg/l in water from various wells in the Boise region where the Project plans to obtain hot water. Four techniques for removing fluorides from water have been studied extensively during the past 15 years or so. Electrodialysis and reverse osmosis are useful in reducing total dissolved solids from brackish water, but are nonspecific and are too expensive for treatment of the Boise geothermal water. Selective precipitation is a widely used technique for treating water, but would also prove expensive for the Boise geothermal water because of the relatively high solubility of fluoride salts and consequently high concentration (and cost) of precipitants required to reduce the fluorides to an acceptable level. Ion-exchange separation using activated alumina as the exchange medium appears to be the most promising technique and we recommend that some laboratory and pilot studies be conducted to establish suitability and operating boundaries.

147 (UCID--19208) APPROACH TO RECOVER
STRATEGIC METALS FROM BRINES. Raber, E.;
Harrer, J.; Gregg, D. (Lawrence Livermore
National Lab., CA (USA)). 16 Sep 1981.
Contract W-7405-ENG-48. 15p. NTIS, PC A02/
MF A01. Order Number DE82003921.

The objective of the proposed research is to evaluate hypersaline brines from geothermal sources and salt domes as possible sources for some strategic metals. This research is suggested because several previous analyses of brine from geothermal wells in the Imperial Valley, California, and from Gulf Coast salt domes, indicate near commercial values for platinum as well as other metals (i.e., gold, silver). Extraction of the platinum should be technically feasible. A research program should include more complete systematic sampling and analysis for resource delineation, followed by bench-scale investigation of several potential extraction processes. This could be followed by engineering feasibility and design studies, for extraction of the metals either as a by-product of other operations or in a stand-alone process.