**GULF COAST GEOPRESSURED - GEOTHERMAL
PROGRAM SUMMARY REPORT COMPILATION**

DOE/ID/13366--71-Vol. 3

VOLUME III

**APPLIED AND DIRECT USES, RESOURCE
FEASIBILITY, ECONOMICS**

WORK PERFORMED UNDER U.S. DEPARTMENT OF ENERGY
CONTRACT NO. DE-FG07-95ID13366

Chacko J. John, Gina Maciasz, Brian J. Harder
Basin Research Institute
Louisiana State University
208 - Howe Russell Geoscience Complex
Baton Rouge, LA 70803-4101
Phone: 504-388-8328

JUNE, 1998

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

**GULF COAST GEOPRESSURED - GEOTHERMAL
PROGRAM SUMMARY REPORT COMPILATION**

VOLUME III

**APPLIED AND DIRECT USES, RESOURCE
FEASIBILITY, ECONOMICS**

WORK PERFORMED UNDER U.S. DEPARTMENT OF ENERGY
CONTRACT NO. DE-FG07-95ID13366

Chacko J. John, Gina Maciasz, Brian J. Harder
Basin Research Institute
Louisiana State University
208 - Howe Russell Geoscience Complex
Baton Rouge, LA 70803-4101
Phone: 504-388-8328

JUNE, 1998

DISCLAIMER

This report was prepared as an account of work sponsored by the U.S. Government. Neither the U.S. Government nor the U.S. Department of Energy, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, mark, manufacture, or otherwise, do not necessarily constitute or imply its endorsement, recommendations, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

TABLE OF CONTENTS

GEOPRESSURED - GEOTHERMAL HYBRID CYCLE POWER PLANT, DESIGN TESTING AND OPERATION SUMMARY	1
THE FEASIBILITY OF HYDRAULIC ENERGY RECOVERY FROM GEOPRESSURED - GEOTHERMAL RESOURCES	16
Economic Analysis of the Pelton turbine	24
BRINE PRODUCTION AS AN EXPLORATION TOOL FOR WATER DRIVE GAS RESERVOIRS	28
STUDY OF SUPERCRITICAL RANKINE CYCLES	33
APPLICATION OF THE GEOPRESSURED-GEOTHERMAL RESOURCE TO PYROLYTIC CONVERSION OR DECOMPOSITION/DETOXIFICATION PROCESSES	47
Pyrolytic Conversion	50
Supercritical Water Oxidation (SCWO)	51
Other High Temperature/High Pressure Processes	54
Technical Evaluation	55
CONCLUSIONS	65
Wet Air Oxidation (WAO)	65
Pyrolytic Conversion	65
Decomposition/Detoxification Process	66
CO-LOCATION OF MEDIUM TO HEAVY OIL RESERVOIRS WITH GEOPRESSURED - GEOTHERMAL RESOURCES AND THE FEASIBILITY OF OIL RECOVERY USING GEOPRESSURED - GEOTHERMAL FLUIDS	67
ECONOMIC ANALYSIS	90
APPLICATION OF GEOPRESSURED - GEOTHERMAL RESOURCES TO DIRECT USES	95
INDUSTRIAL CONSORTIUM FOR THE UTILIZATION OF THE GEOPRESSURED - GEOTHERMAL RESOURCE	103
POWER GENERATION	105

INDUSTRIAL	105
Desalination	106
Gas Use and Sales	106
Pollutant Removal	106
Thermal Enhanced Oil Recovery	107
Sulfur Frasching	107
Petroleum and Natural Gas Pipelining	108
Coal Desulfurization and Preparation	108
Lumber and Concrete Products Kilning	108
AGRICULTURE AND AQUACULTURE APPLICATIONS	109
Greenhousing	109
Production Plot Warming and Frost Protection	110
Rearing of Fish. Crustaceans. Exotics. Turtles. and Alligators	110
Processing	111
PAPER AND CANE SUGAR INDUSTRIES	112
CHEMICAL PROCESSING	112
ECONOMICS	114
ENVIRONMENTAL CONSIDERATIONS FOR GEOPRESSURED - GEOTHERMAL DEVELOPMENT	118
APPENDIX - 1	124
APPENDIX - 2	129
APPENDIX - 3	137

LIST OF FIGURES

Figure 1. - - Hybrid cycle flow diagram (from, Hughes, 1987).	4
Figure 2. - - Hybrid cycle flow diagram (from, Hughes, 1987).	5
Figure 3. - - Three types of turbines (from, Thurston and Plum, 1991)	19
Figure 4. - - Graph showing specific speed vs. turbine power for various speeds and pressures (from, Thurston and Plum, 1991).	21
Figure 5. - - The Pelton turbine for geopressure energy recovery (from, Thurston and Plum, 1991).	23
Figure 6. - - Cross section of a geopressed sandstone reservoir (Randolph, 1982).	30
Figure 7. - - Geopressed - geothermal energy production (from, Goldsberry, 1982).	36
Figure 8. - - Power cycle matching to cooling and heating curves for the heat source and sink (from, Goldsberry, 1982).	38
Figure 9. - - Schematic illustrations showing the power cycle component comparison (from, Goldsberry, 1982).	41
Figure 10. - - Supercritical power cycle with control scheme (from, Goldsberry, 1982)	45
Figure 11. - - Conceptual process flow diagram: decomposition/detoxification process for 1000,000 GPD (455,000) L/d). (from, Propp, et.al., 1991).	58
Figure 12. - - Geographic locations of heavy oil fields in the United States (from, Dietzman et al., 1965).	69
Figure 13. - - Map of southwest Louisiana showing locations of recorded occurrences (indicated by black dots on the map) of 20° - 25° API gravity oil at shallow depth (< 3,001 ft.) and the geologic age trends (from, John, 1992).	72
Figure 14. - - Map of Calcasieu Parish, Louisiana, showing fields with < 25° API gravity oil at shallow depths (< 3,001 ft.) and located in the Frio geopressed - geothermal trend (from, John, 1992)	73
Figure 15. - - Schematic flow chart illustrating a geothermally enhanced oil recovery method utilizing geothermal water from reservoirs in the Wilcox to inject shallow heavy oil reservoirs in the Jackson Group (from, Seni and Walter, 1993).	75

Figure 16. - - Map of oil plays in Texas containing medium to heavy oil reservoirs. Numbers indicate names of fields listed on the left side of this figure (from, Seni and Walter, 1993).	77
Figure 17. - - Location map of heavy oils of South Texas showing the Mirando trend and the location of the Alworth Field (from, Negus de-Wys et.al., 1991, in Hamlin et.al., 1990).	79
Figure 18. - - Graph of API gravity versus depth for all large oil reservoirs in Texas (from, Seni and Walter, 1993).	81
Figure 19. - - Graph of average API gravity versus depth for all oil plays in Texas (from, Seni and Walter, 1993).	83
Figure 20. - - Map showing the location of deep abandoned gas wells, oil fields in the Upper Jackson, and the South Texas geothermal corridor. A 2.5 miles radius around the abandoned gas wells intercepts more than half of all heavy oil reservoirs in the geothermal corridor. Table 18 lists the following data for numbered abandoned gas wells: unique BEG identification number, operator/well name, field and reservoir (from, Seni and Walter, 1993).	86
Figure 21. - - (A) Structure map on top of the Cole Sandstone, Alworth Field. (B) Isopach map of the oil column in the Cole Sandstone, Alworth Field (from, Negus de-Wys et.al., 1991).	88
Figure 22. - - Diagram illustrating the utilization of the geopressured - geothermal resource (from, Negus de-Wys and Darfman, 1990, in, Industrial Consortium for the utilization of The geopressured - geothermal resource, ed. J. Negus de-Wys, Volume 1).	97
Figure 23. - - Temperature requirements for potential applications of the geopressured - geothermal resource at a well site (from, Lunis et.al., 1991).	98
Figure 24. - - Schematic illustration of a feasible desalination facility using the geopressured - geothermal resource (from, Lunis et.al., 1991).	100
Figure 25. - - Schematic illustration of a feasible desalination / agriculture / aquaculture complex using the geopressured - geothermal resource (from, Lunis et.al., 1991).	101
Figure 26. - - Conceptual layout of a geopressured integrated facility (from, Lunis, 1990).	104
Figure 27. - - Extraction of bromine from seawater or selected brines (DOW process, modified) (from, Lunis et.al., 1991).	115

LIST OF TABLES

TABLE 1	Summary of Hybrid Cycles Power Production	7
TABLE 2	Breakeven price to produce electricity from a geopressured-geothermal resource for selected cases, 1990 dollars	10
TABLE 3	Breakeven price to produce electricity from a geopressured-geothermal resource producing 20,000 bpd, 1990 dollars	11
TABLE 4	Breakeven price to produce electricity from a geopressured-geothermal resource additional production scenarios, 1990 dollars	12
TABLE 5	Energy Utilization	17
TABLE 6	Range of conditions for a typical geopressured - geothermal well	22
TABLE 7	Effect of well life on breakeven cost	27
TABLE 8	Power Plant Energy Balance	43
TABLE 9	Common Basis Power Plant Cost Estimates	44
TABLE 10	Estimated Geopressured-Geothermal Brine Recoverable Energy Content Content Calculation	46
TABLE 11	Resource description	49
TABLE 12	Substances treated by supercritical water oxidation (SCWO)	56
TABLE 13	Process parameters for SCWO	59
TABLE 14	Energy balance for a 100,000 GPD (455,000 L/d) processing plant utilizing air as the oxidizing medium	60
TABLE 15	Energy balance for a 100,000 GPD (455,000 L/d) processing plant utilizi ng 99% oxygen as the oxidizing medium	61
TABLE 16	Breakeven cost for three selected levels of uncertainty	64
TABLE 17	Comparative statistics of large heavy-, medium-, and light-oil reservoirs in Texas	80

TABLE 18	Abandoned Deep Gas Wells in South Texas	85
TABLE 19	Summary reservoir data sheet, Alworth Field, South Texas	89
TABLE 20	Economic input data for evaluation of Alworth Field	91
TABLE 21	Production Scenario 1.	94
TABLE 22	Principal direct use applications in the United States, (from, Lunis, 1990 in, Industrial consortium for the utilization of the geopressed - geothermal resource: Volume 1, ed. J. Negus de-Wys).	102
TABLE 23	Pleasant Bayou Brine Analysis	113
TABLE 24	Probability and Severity of Potential Environmental Impacts of Direct Use Projects	120
TABLE 25	Regulations Affecting Geothermal Energy Development	121

GEOPRESSURED - GEOTHERMAL HYBRID CYCLE POWER PLANT,

DESIGN TESTING AND OPERATION SUMMARY

This summary was compiled from the following reports:

Campbell, R.G., and M.M. Hattar, 1991, Design and Operation of a geopressured - geothermal hybrid cycle power plant: Final Report V. 1 and V. 2 by Ben Holt Co., Pasadena, CA for Eaton Operation Co., Inc., and the U.S. Department of Energy, DOE Contract No. DE-AC07-85ID12578, Holt Project No. 30008, V. 1, p. 180, V. 2, Appendices A-K.

Hughes, E.E., 1986, Gas/geothermal hybrid experiment, in, DOE/GRI Industry Meeting March 4-5, 1986, Review of Geopressured - geothermal and co-production research: Idaho National Engineering Laboratory, EG&G, Idaho, DOE Contract No. DE-AC07-76ID01570, Appendix 8.

Plum, M.M., J. Negus-deWys, D.D. Faulder, B.C. Lunis, 1989, Economic review of the geopressured - geothermal resource with recommendations: Idaho National Engineering Laboratory, EG&G, Idaho, EGG-2581, DOE Contract No. DE-AC07-76ID01570, 20 p. and Appendices A-D.

Geopressured-geothermal resources can contribute significantly to the national electricity supply once technical and economic obstacles are overcome. From an economic standpoint, the cost of building and operating power plants, along with the cost of wells and the productive life of the reservoirs, are primary concerns. From a technical standpoint, operation of a power plant with the corrosive, highly saline brine and impure wellhead gas presents special problems.

Power plant performance under the harsh conditions of a geopressured resource was unproven, so a demonstration power plant was built and operated on the Pleasant Bayou

geopressured resource in Texas. This one megawatt facility provided valuable data over a range of operating conditions. In addition, an extended run at maximum power production demonstrated that power can be produced reliably with no serious operating problems.

The basic concept was to use a hybrid cycle to efficiently produce electrical power at acceptable economic cost. Hybrid cycles have a thermodynamic advantage over stand-alone binary cycle and fossil fuel power plants. In the hybrid cycle used at Pleasant Bayou, the advantage occurred because heat which was rejected from the gas engines was utilized in the binary cycle. Because this heat was available at a higher temperature than heat from the geothermal brine, the thermodynamic efficiency of the binary cycle was increased.

Primary goals of the hybrid power system (HPS) experiment were to demonstrate, for the first time, the generation of electricity from a geopressured resource and to gain operating data over an extended time period. The goal of the initial test period was to operate the HPS over a wide range of operating situations, including off-design conditions to obtain data helpful for the design of future commercial operations. A period of operation at maximum power output followed. This longer period of operation constituted an evaluation of the reliability of the HPS and provided the opportunity to develop and document those features of design, operation, and maintenance that are important for achieving high reliability.

As part of program, The Ben Holt Co. built and successfully operated a hybrid cycle power plant at the Pleasant Bayou site. This plant efficiently recovered the energy of a geopressured-geothermal resource. Design of this plant and procurement of equipment for the Pleasant Bayou facility were completed under a separate contract with EPRI. Much of the equipment used at Pleasant Bayou was from DOE's Direct Contact Heat Exchange facility

(DCHX) in East Mesa, California.

This power plant was a first-of-a-kind demonstration of the hybrid cycle concept (see Figures 1&2). A hybrid cycle was used to take advantage of the fact that geopressed resources contain energy in more than one form - hot water and natural gas. Studies have shown that hybrid cycles can yield thirty percent more power than stand-alone geothermal and fossil fuel power plants operating on the same resource. In the hybrid cycle at Pleasant Bayou, gas was burned in engines to generate electricity directly. Exhaust heat from the engines was then combined with heat from the brine to generate additional electricity in a binary cycle. Heat from the gas engine was available at high temperature, thus improving the efficiency of the binary portion of the hybrid cycle.

Hydraulic energy is also available from a geopressed resource due to the high pressure of the wellhead fluid. This energy can be recovered using a pressure reduction turbine. A pressure reduction turbine was not included in the Pleasant Bayou experiment.

Demonstration of the hybrid concept on a geopressed well has the benefit of testing what is estimated to be the thermodynamically optimum way to produce electricity from geopressed resources. Much was learned about potential problems such as scaling, corrosion, flow instabilities, and gas engine life with impure wellhead gas.

The hybrid power system demonstration at Pleasant Bayou was successful in all respects. Design power output was achieved, and 3,445 MWh of power were sold to the local utility over the course of the test. Plant availability was 97.5% and the capacity factor was 80.2% for the extended run at maximum power production. The hybrid cycle power plant demonstrated that there are no technical obstacles to electricity generation at Pleasant Bayou. Even better results can

HYBRID CYCLE FLOW DIAGRAM KEY FLOWS SHOWN

Figure 1. - - Hybrid cycle flow diagram (from, Hughes, 1987).

HYBRID CYCLE FLOW DIAGRAM KEY OPERATING CONDITIONS SHOWN

Figure 2. - - Hybrid cycle flow diagram (from, Hughes, 1987).

be expected with current technology and new equipment

The hybrid concept can be used to improve the utilization efficiency of energy resources. More electricity can be generated from two energy sources in a hybrid cycle than by using each separately to generate electricity. This occurs because heat which would be wasted from one energy source is utilized in combination with heat from the other source.

Under EPRI contract RP1673-4, The Ben Holt Co. evaluated methane/hot water hybrid cycles for hydrothermal and geopressured-geothermal applications. Hybrid cycles were calculated to generate as much as thirty percent more electricity than if the methane was used in a fossil fuel power plant and the hot water in a binary cycle power plant. Results from that evaluation are summarized in Table 1. This table is based on optimized hybrid cycles where enough methane is combusted so that exhaust heat provides all necessary energy to vaporize the working fluid. This requires a methane to hot water ratio higher than is found in a geopressured resource.

Hybrid cycles have another important benefit in that they can be used to provide a base load of power in case of an interruption in supply of one of the energy sources. For instance, the binary cycle portion of a geothermal hybrid plant could continue to operate even if the fossil fuel portion of the hybrid plant was shut down due to lack of fuel. The efficiency of the binary cycle would drop if this occurred, but electricity generation could continue.

Development of a resource in stages is another potential benefit of hybrid cycles. A developer could install a binary cycle on a geothermal resource with the potential for adding a gas engine or gas turbine and utilizing the waste heat. Cash flow from the binary cycle electricity sales could contribute to the financing of the conversion to hybrid. Converting a binary cycle to hybrid also has an important advantage if the geothermal resource is unknown. A binary cycle could be

TABLE 1

SUMMARY OF HYBRID CYCLES POWER PRODUCTION

Gas Turbine Heat Rate = 9.850 BTU/KWH

Brine Temp. Difference (°F)	Hybrid (MW Net)	Binary + Fossil (MW Net)	Difference (MW)	(%)
280	24.11	20.09	4.02	20.0
330	20.58	17.49	3.09	17.7
360	18.37	15.93	2.44	15.3

Gas Turbine Heat Rate = 11.350 BTU/KWH

Brine Temp. Difference (°F)	Hybrid (MW Net)	Binary + Fossil (MW Net)	Difference (MW)	(%)
280	19.42	15.40	4.02	26.1
330	16.48	13.39	3.09	23.1
360	14.77	12.33	2.44	19.8

Gas Turbine Heat Rate = 14.166 BTU/KWH

Brine Temp. Difference (°F)	Hybrid (MW Net)	Binary + Fossil (MW Net)	Difference (MW)	(%)
280	17.07	13.05	4.02	30.8
330	15.05	11.96	3.09	25.8
360	13.81	11.38	2.44	21.4

NOTE: Brine Flow Rate = 500,000 lb/hr for all cases.

(From, Ben Holt Co., Final Report, V. 1, 1991).

installed first, and if the geothermal resource has limited production or lower than design temperature, the fossil fuel portion of the plant could be designed to compensate. In any case where a binary cycle is to be converted to hybrid, it is important to select the binary cycle turbine, circulating pump, and other equipment such that they will be adequate for the hybrid service.

Before the demonstration at Pleasant Bayou, serious concerns about the viability of power production from a geothermal-geopressured resource existed. These concerns included scaling and corrosion due to the high salinity brine, engine operation on impure wellhead gas, and mechanical problems associated with the large temperature difference in E-3-N.

The concerns about operating a commercial power plant on the Pleasant Bayou resource were favorably resolved. Scale and corrosion inhibitors were shown to be effective throughout the operating range of brine temperatures. Equipment and piping did not corrode during the nine-month test. Wear was not extensive for the length of operation. As a result, carbon steel can be used throughout a commercial plant except for those vessels and pipes which come in contact with the high temperature exhaust gas... By using carbon steel as the primary material of construction, the cost of the power plant can be kept in line with other binary cycle power plants which are commercially competitive.

Both brine heat exchangers exceeded design specifications, heat exchanger fouling due to scale deposition from the high salinity brine was not a problem. During the design phase, there were many mechanical design concerns about E-3-N. These concerns were due to high temperature operation and to the large temperature difference between the inlet exhaust gas and the outlet isobutane temperature. The unique exchanger design successfully solved the thermal stress problem. This exchanger was built of 304 SS and showed no sign of corrosion. Also, there

was no sign of wear between the tubes and the tubesheet support due to vibration.

The turbine operated 2902 hours. Vibration monitors provided insight into turbine operation and prevented catastrophic turbine failure. There was only one significant problem encountered during the test. Carbon deposits from the gas engine exhaust caused fouling of the heat exchange surface, thus degrading performance. Possible solutions to the problem of excessive fouling in the exhaust gas exchanger include replacing the gas engine with a gas turbine, using an engine which more efficiently completes combustion, or filtering the exhaust stream

Prior to construction of the plant at Pleasant Bayou an economic analysis was run to determine breakeven price needed to make the hybrid plants economically viable. The economic results made prior to testing are summarized and follow. The breakeven price is a minimum per unit charge required for the developer to recover all direct and indirect costs and a rate of return sufficient to compensate the developer for depreciation, the time value of money, and the risk of failure. The results are presented in Tables 2, 3, and 4).

Table 2 presents the breakeven price to produce electricity or electricity plus methane for the eight cases. Comparing all cases, the hypothetical Best Case has the lowest breakeven price and the hypothetical Worst Case has the highest breakeven price. When comparing all production scenarios, scenario D (15% discount rate and 0% escalation) has the lowest breakeven price because the economic assumptions are less conservative and all energy forms are exploited. Comparing existing well conditions, South Texas 400 and 500 have the lowest breakeven price, primarily because of the higher reservoir temperature and higher gas content. The Hulin Well has the lowest breakeven price of the DOE design wells, again primarily because of these higher reservoir temperature.

TABLE 2

Breakeven price to produce electricity from a geopressured-geothermal resource for selected cases, 1990 dollars

CASE	WELL ASSUMPTIONS					ELECTRICAL GENERATION PLANT			RESOURCE LIFE	15% DISCOUNT			26% DISCOUNT				
	BARRELS (per day)	TOP WHP (psi)	GAS CONT. (scf/b)	METHANE (%)	TEMP (°F)	GENERATOR TYPE	In 000's 1990 dollars	CAPACITY (kW)		3% ESC A	3% ESC D	0% ESC D	3% ESC A	3% ESC B	3% ESC C	3% ESC D	0% ESC D
1. WORST CASE	10,000	800	20	85%	255	gas geothermal hydraulic	267 760 20	606 380 33	5 •	\$0.604 20.10 •	\$0.365 •	\$0.342 •	\$0.707 23.50 •	\$0.031 •	\$0.041 •	\$0.428 •	\$0.404 •
2. GLADYS McCALL	40,000	800	27	85%	268	gas geothermal hydraulic	1,441 3,700 79	3,275 1,850 132	5 10	\$0.182 6.05 0.168 5.60	\$0.122 0.114	\$0.114 0.103	\$0.215 7.15 0.201 6.70	\$0.031 0.028	\$0.041 0.038	\$0.145 0.136	\$0.137 0.126
3. GLADYS McCALL	25,000	800	27	85%	268	gas geothermal hydraulic	902 2,320 120	2,050 1,160 200	5 10	\$0.249 8.30 0.231 7.70	\$0.156 0.147	\$0.146 0.132	\$0.293 9.75 0.272 9.05	\$0.031 0.028	\$0.041 0.038	\$0.185 0.173	\$0.174 0.161
4. PLEASANT BAYOU	25,000	1,350	24	85%	287	gas geothermal hydraulic	800 2,840 140	1,819 1,420 234	5 10	\$0.241 8.05 0.225 7.50	\$0.158 0.149	\$0.149 0.135	\$0.285 9.50 0.266 8.85	\$0.031 0.028	\$0.041 0.038	\$0.188 0.177	\$0.172 0.164
5. MULIN	15,000	3,400	40	93%	330	gas geothermal hydraulic	876 2,602 287	1,991 1,301 479	5 10	\$0.232 7.70 0.214 7.10	\$0.140 0.131	\$0.132 0.119	\$0.273 9.10 0.252 8.50	\$0.031 0.028	\$0.041 0.038	\$0.166 0.155	\$0.157 0.144
6. BEST CASE	40,000	3,400	60	93%	330	gas geothermal hydraulic	3,579 6,900 766	8,134 3,450 1,276	• 10	• 0.106 3.55	• 0.071	• 0.065	• 0.127 4.25	• 0.028	• 0.038	• 0.086	• 0.079
7. SOUTH TEXAS 400 °F	20,000	500	62	95%	380	gas geothermal hydraulic	1,849 5,220 0	4,202 2,610 0	5 10	\$0.149 4.95 0.137 4.60	\$0.105 0.098	\$0.099 0.089	\$0.177 5.90 0.165 5.50	\$0.031 0.028	\$0.041 0.038	\$0.126 0.118	\$0.119 0.110
8. SOUTH TEXAS 500 °F	20,000	500	100	95%	480	gas geothermal hydraulic	2,982 9,086 0	6,778 4,543 0	5 10	\$0.119 3.95 0.109 3.45	\$0.089 0.082	\$0.083 0.075	\$0.143 4.75 0.132 4.40	\$0.031 0.028	\$0.041 0.038	\$0.107 0.100	\$0.101 0.092
Note: Breakeven price for scenario "A" is for kWh and mcf. Breakeven price for scenarios "B", "C", and "D" is for kWh only.																	
An "•" denotes a scenario not applicable for study.																	

(From, Plum et. al., 1989).

TABLE 3

Breakeven price to produce electricity from a geopressed-geothermal resource producing 20,000 bpd, 1990 dollars

CASE	WELL ASSUMPTIONS					ELECTRICAL GENERATION PLANT				15% DISCOUNT			26% DISCOUNT				
	BARRELS (per day)	TOP VHP (psi)	GAS CONT. (scf/b)	METHANE (%)	TEMP (°F)	GENERATOR TYPE	In 000's 1990 dollars	CAPACITY (kW)	RESOURCE LIFE	3% ESC A	3% ESC D	0% ESC D	3% ESC A	3% ESC B	3% ESC C	3% ESC D	0% ESC D
7. SOUTH TEXAS 400 °F	20,000	500	62	95%	380	gas	1,849	4,202	5	\$0.149	\$0.105	\$0.099	\$0.177	\$0.031	\$0.041	\$0.126	\$0.119
						geothermal	5,220	2,610	10	4.95			5.90				
						hydraulic	0	0		0.137	0.098	0.089	0.165	0.028	0.038	0.118	0.110
										4.60			3.50				
8. SOUTH TEXAS 500 °F	20,000	500	100	95%	480	gas	2,982	6,778	5	\$0.119	\$0.089	\$0.083	\$0.143	\$0.031	\$0.041	\$0.107	\$0.101
						geothermal	9,086	4,543	10	3.95			4.75				
						hydraulic	0	0		0.109	0.082	0.075	0.132	0.028	0.038	0.100	0.092
										3.45			4.40				
9. MULIN	20,000	3,000	40	93%	330	gas	1,168	2,654	5	\$0.192	\$0.121	\$0.114	\$0.227	\$0.031	\$0.041	\$0.144	\$0.136
						geothermal	3,460	1,730	10	6.40			7.55				
						hydraulic	330	550		0.177	0.113	0.102	0.210	0.028	0.038	0.134	0.125
										5.90			7.00				
10. PLEASANT BAYOU	20,000	1,500	24	85%	287	gas	640	1,455	5	\$0.268	\$0.168	\$0.162	\$0.316	\$0.031	\$0.041	\$0.199	\$0.192
						geothermal	2,280	1,140	10	8.90			10.55				
						hydraulic	132	220		0.248	0.161	0.146	0.294	0.028	0.038	0.191	0.177
										8.30			9.80				
11. GLADYS McCALL	20,000	1,000	27	85%	268	gas	720	1,637	5	\$0.278	\$0.173	\$0.162	\$0.327	\$0.031	\$0.041	\$0.204	\$0.193
						geothermal	1,860	930	10	9.25			10.90				
						hydraulic	66	110		0.256	0.164	0.148	0.303	0.028	0.038	0.194	0.180
										8.55			10.10				

Note: Breakeven price for scenario "A" is for kWh and mcf.
Breakeven price for scenarios "B", "C", and "D" is for kWh only.

(From, Plum, et.al., 1989).

TABLE 4

Breakeven price to produce electricity from a geopressured-geothermal resource, additional production scenarios, 1990 dollars

All cases assume:

26% discount rate
 5% inflation, 0% escalation
 11% interest rate, 40% debt ratio
 38% federal and 5% state corporate tax
 5% severance and 0.3% ad valorem local tax
 15% royalty

SCENARIOS	WELL ASSUMPTIONS			ELECTRICAL GENERATION PLANT			RESOURCE LIFE	BREAKEVEN \$ / unit Production
	BARRELS (per day)	GAS CONT. (scf/b)	TEMP. (°F)	GENERATOR TYPE	In 000's 1990 dollars	CAPACITY (kW)		
Most likely production possibility for Gladys McCall								
D. Base case, Gladys McCall Produce electricity from all energy sources	25,000	27	288	gas geothermal hydraulic	902 2,320 120	2,050 1,160 200	10	0.161/kwh
Sensitivity studies of production possibilities for Gladys McCall								
E. Sell only natural gas Produce no electricity	25,000	27	288	gas geothermal hydraulic	0 0 0	0 0 0	10	11.55/mcf
F. No well rework costs Drill \$5,000,000 production well Produce electricity from all energy sources	25,000	27	288	gas geothermal hydraulic	902 2,320 120	2,050 1,160 200	10	0.199/kwh
G. No well rework costs Drill \$10,000,000 production well Produce electricity from all energy sources	25,000	27	288	gas geothermal hydraulic	902 2,320 120	2,050 1,160 200	10	0.265/kwh
H. 20 y production schedule Production decline begins y-11 Power production for 25,000 BPD, 8% maintenance Produce electricity from thermal and gas energy sources	25,000 to 10,000	27	288	gas geothermal hydraulic	902 2,320 0	2,050 1,160 0	20	0.161/kwh
I. 20-y production schedule Develop 2 production wells, 2nd developed in year-5 No Production decline, alternate equipment every 5 years Produce electricity from all energy sources	25,000	27	288	gas geothermal hydraulic	902 2,320 120	2,050 1,160 200	20	0.178/kwh
J. 10-y production schedule Production decline begins y-1 Assume average power production 40,000 bpd Produce electricity from thermal and gas energy sources	40,000 to 10,000	27	288	gas geothermal hydraulic	902 2,320 0	2,050 1,160 0	10	0.152/kwh

(From, Plum et.al., 1989).

From Table 2 it can be seen that the resources with higher temperatures and increased gas content in the South Texas cases result in breakeven costs of about \$0.09 to \$0.10/kWh with off-the-shelf technology. This is within the program goals. Using available advanced technology results in \$0.045 to \$0.05/kWh. This is a dramatic example of the effect of higher quality resources (higher temperature and more gas) on the breakeven cost to produce electricity.

Table 2 also suggests the economic advantage of using the hydraulic and methane energy sources. The results for Option A suggest that using only the thermal energy is uneconomic because the breakeven price ranges from \$0.11 to \$0.60/kWh and \$3.65 to \$20.10/MCF, both of which are well above current market prices. This uneconomic position is a result of the fact that the model allocates the development and operation costs to the thermal plant and relatively low resource temperatures. The breakeven price drops to a range of \$0.10 to \$0.43/kWh when the production output is increased by using relatively inexpensive hydroelectric and gas turbines (Note: no breakeven price for methane gas is provided because all of the methane is burned by the gas turbine). Both Scenario B and C suggest that utilizing the hydraulic and methane energy lowers the breakeven cost. However, Scenario B and C do not suggest that a developer should develop a geopressure-geothermal resource using only hydroelectric or only gas turbines because these incremental units have been added on and have not amortized the pre-development, development, operation, or post operation costs.

Because of the wide variability in flow, temperature, gas content, and total dissolved solids in a geopressured-geothermal resource, the analysis assumed a situation where all cases produced brine at a constant production rate of 20,000 bpd presented in Table 3. Based on the experience with the program design wells, 20,000 bpd is a realistic production rate. The results

suggest that selecting a resource with higher temperatures is the most effective tool in reducing the breakeven cost to produce electricity. Developing all, energy forms will, also reduce the cost. The South Texas resources have a lower breakeven price at a 20,000 bpd production rate because of the higher temperature and increased gas content. Increasing the brine production rate of the Hulin resource from 15,000 to 20,000 bpd reduces its breakeven price about \$0.15 to about \$0.13/kWh because plant capacity is increased while assuming identical pre-development and production well costs. Reducing the brine production rate of the Gladys McCall resource from 25,000 to 20,000 bpd increases its breakeven price from about \$0.165 to \$0.185/kWh because plant capacity has decreased with identical, pre-development and production well costs.

The geopressured-geothermal program on Hybrid Power Systems have the following broad conclusions about the development of geopressured-geothermal resources: (1) Conversion of the Geopressured-Geothermal resource to electricity is expensive. Assuming the characteristics of the geopressured-geothermal resources encountered in the DOE design wells, the cost to convert geopressured-geothermal energy to electricity continues to be higher (\$0.13 to \$0.27/kWh) than conventional energy sources because of the relatively higher development costs per unit of capacity and typically low temperatures of the produced brine. Developing the hydraulic and methane gas reduces the breakeven price for a resource. This is because all development costs have been allocated to thermal energy conversion and the incremental cost to develop the hydraulic and methane gas energy is the amortized value of only the generation equipment. (2) Higher quality Geopressured-Geothermal resources will tend to be developed prior to lower temperature geopressured-geothermal resources with less gas. Every geopressured-geothermal resource has differing resource characteristics (temperature and gas content) making

one resource more economical to develop than another. Given identical market conditions, resources with the higher energy content will usually be developed first because the breakeven price for commercial production is lower. New technologies that could reduce the breakeven price of marginal geopressured-geothermal resources would also reduce the breakeven price of the higher energy-value resources; in effect, geopressured-geothermal resources with higher temperatures and higher quality gas characteristics will usually be developed before marginal resources, even with advanced technological improvements. (3) Technological improvements for utilization of the geopressured geothermal resources have potential. Currently, there is no commercial development of geopressured-geothermal energy. Typical of any immature industry, better technologies and development strategies will be developed that can potentially reduce the breakeven cost to successfully market energy. This could be accomplished by reducing initial investment and operating costs and increasing energy conversion efficiencies. (4) To be economically viable, geopressured-geothermal wells must be selected from reservoirs characterized by higher wellhead temperatures, higher gas/water ratios, and employ advanced energy conversion technologies. This economically driven selectivity will greatly reduce the estimated recoverable geopressured-geothermal resources and locate viable projects in the hotter, more gaseous geopressured-geothermal stratigraphic sections. (5) The test at Pleasant Bayou showed the technical feasibility of a commercial power plant. The economic feasibility remains to be assessed. Choosing a working fluid would be part of an economic study. Propane produces more power per pound of brine, but it also has a higher vapor pressure, so equipment cost is higher. An economic analysis based on the relative price of electricity and natural gas would determine whether a hybrid power cycle or a binary power cycle in which the gas is sold to a

distributor. An economic analysis would assess if a pressure reduction turbine should be used to recover hydraulic energy. No economic analysis was done after testing of the hybrid power plant as the Geopressure-Geothermal program emphasis moved to other areas.

THE FEASIBILITY OF HYDRAULIC ENERGY RECOVERY FROM GEOPRESSURED - GEOTHERMAL RESOURCES

This report was authored by Glenn C. Thurston and Martin M. Plum (Report No. EGG-EP-9841) September 1991, and presented the results of a technical and economic feasibility study conducted by the Idaho National Engineering Laboratory (INEL) for DOE under DOE Contract No. DE-AC07-76ID01570. The information compiled here on this topic is taken directly from this report.

This study was directed to the conversion of the hydraulic energy into work and specifically to energy recovery where the available pressure drop is in the range of 700 - 2000 psi. The hydraulic energy is contained in the high pressure fluid available from a geopressured - geothermal well. Flowing wellhead pressured in a typical well of this type ranges between 2000 - 3500 psia. In addition to the hydraulic energy, geopressured - geothermal reservoirs also contain chemical energy in the form of gas and mostly methane, dissolved in the brine, and thermal energy which is in the high temperature of the brine. Table 5 lists the many uses proposed for these forms of energy. In the Pleasant Bayou Hybrid Power System (HPS) all forms were initially proposed to be converted to electrical energy, but the system was finally operated without the recovery of hydraulic energy as off-the-shelf equipment to perform the conversion could not be obtained. It was estimated that the addition of a hydraulic turbine would have added 7 to 8% to

TABLE 5
ENERGY UTILIZATION

Process	Fluid	State	Press PSIA	Temp F	Enthalpy BTU/Lb	Isentropic Work or Q BTU/Lb	Efficiency	Net Work Watt-Hr per Lb	Net Work BTU/Lb	Cooling system
Pelton Turbine	compressed liquid	Turbine Inlet	2200.0	282.41	255.88	6.36	.80	1.49	5.09	not required
		Turbine Outlet	200.0	280.0	249.52					
2 Phase Expander	comp.liqd.	Expander Inlet	200.0	280.0	249.52	3.85	.50	.57	1.93	non- condensing
	2 phase	Expander Outlet	14.7	212.0	245.57					
2 Phase Expander	comp.liqd.	Expander Inlet	200.0	280.0	249.52	12.90	.50	1.89	6.45	air cooled
	2 phase	Expander Outlet	3.72	150.0	235.62					
2 Phase Expander	comp.liqd.	Expander inlet	200.0	280.0	249.67	27.63	.50	4.05	13.81	liquid cooled
	2 phase	Expander Outlet	.70	90.0	221.89					
Binary Cycle	comp.liqd.	Heat Exchanger In	200.0	280.0	249.67	121.08		3.0 to 4.0	10.23 to 13.65	liquid cooled
	comp.liqd.	Heat Exchanger Out	200.0	160.0	123.44					

(From, Thurston and Plum, 1991)

the net energy produced by the plant.

There are different devices that can potentially be used for the hydraulic expander and specific speed is an indicator of the type of device to use. Specific speed relates the parameter of head, power, and speed and for hydraulic turbines it is defined as follows:

$$N_s = N \times \frac{P^{0.5}}{H^{1.25}}$$

where N_s = specific speed in rpm $\times$ hp^{0.5}/ft.^{1.25}

N = rotary speed in RPM

P = power in hp

H = head or pressure drop across the turbine in ft.

The head is the pressure drop through which the machine operates and the power can be varied to some extent by using multiple machines. The three general classes of hydraulic turbines (Figure 3) and their appropriate speed for high efficiency operation are as follows:

- (1) Pelton or impulse ($N_s = 2$ to 8)
- (2) Frances or partial reaction ($N_s = 12$ to 120)
- (3) Kaplan or propeller ($N_s = 80$ to 250)

Using a typical power of 670 hp (500 kw) and a pressure drop of 2000 psi (4922 ft) at 3600 rpm, we get:

$$N_s = 3600 \times \frac{670^{0.5}}{4922^{1.25}} = 2.26$$

This value of 2.26 for specific speed suggests that a Pelton turbine is the most appropriate choice for hydraulic energy recovery from a geopressured - geothermal well source, because of its high efficiency, simple mechanical design, and the fact that the shaft seals have only the turbine

Figure 3. - - Three types of turburries (from, Thurston and Plum, 1991)

back pressure to seal rather than the high inlet pressure.

The probable for hydraulic energy recovery will be in the 2000 - 1000 psi pressure drop range with a power range from 100 to 500 kw. The specific speed for a range of typical geopressure applications are illustrated in Figure 4. The range of conditions for fluid from a typical geopressured - geothermal well is shown in Table 6.

Pelton turbines for the very high heads required in geopressured - geothermal application are not commercially available and the fabrication of such a device would require special first of a kind engineering and tooling which would be a one time cost. The major items to be engineered are the high head turbine wheel, a pressured housing, control needle and housing shaft seal.

A Pelton turbine designed for conditions of geopressured energy recovery is illustrated in Figure 5. It shows the approximate principal dimensions for a 3600 rpm turbine with jet speed of 560 ft/s and a single nozzle capable of producing 500 kw. Development testing is necessary to understand the effect of the dissolved gases, verify cavitation suppression, would be provided by utilizing the gas backpressure of the dissolved methane and carbon dioxide that exists in the geofluid. The detailed turbine design will be influenced by the inlet pressure, temperature, density and gas content and also by the flow rate and allowable discharge pressure.

Further, site specific factors can also significantly influence the usefulness of a hydraulic turbine and the design specification for the turbine. Site specific considerations include available hydraulic pressure drop, expected well life, changes in well flow rate with time, and the chemical and physical properties of the geopressured - geothermal brine. The two major factors limiting the hydraulic turbine design include (1) the pressure drop must not cause excessive turbine stress, the bucket bending stress from a 2000 psi pressure drop is near the upper limit for a Pelton

Figure 4. - - Graph showing specific speed vs. turbine power for various speeds and pressures (from, Thurston and Plum, 1991).

TABLE 6
Range of conditions for a typical geopressed - geothermal well

Bottom hole pressure (psia)	9,800 to 18,500		
Flowing well head pressure (psia)	2,000 to 3,500	used	2200*
Bottom hole temperature (°F)	298 to 360		
Flowing well head temperature (°F)	268 to 330	used	282*
Maximum flow (bpd)	15,000 to 40,000	used	24,514*
Gas/water ratio (scf/bbl)	24 to 50		
Methane (% gas)	85 to 93		
CO ₂ (% gas)	4 to 10		
Total dissolved solids (mg/L)	95,000 to 195,000		
Chlorides (mg/L)	57,000 to 115,000		

*Used in subsequent hydraulic energy analysis for a net output of 500 kW.

(from, Thurston and Plum, 1991)

Figure 5. - - The Pelton turbine for geopressure energy recovery (from, Thurston and Plum, 1991).

turbine, and (2) the back pressure (turbine discharge) must be high enough to suppress cavitation. The pressure for reinjecting the fluid via a disposal well may also limit the turbine discharge pressure. The reinjection pressure may be as high as 500 - 700 psia making it undesirable to expand the geofluid below this pressure.

Economic Analysis of the Pelton turbine

Details of this economic analysis are given in Thurston and Plum (1991) and information compiled here is taken directly from this source. This analysis was conducted using the present value (PV) methodology to calculate the breakeven price to sell energy from a geopressure - geothermal resource. This method is also called the discounted cash flow analysis (DCFA), and is an economic method or process of equating all past, present, and future costs and revenues to a common point of time value. This is the generally preferred method used by economic analysts because cash flows are accounted on a current, common dollar basis which is obtained by discounting all after tax cash values to a PV using a discount rate. This discount rate is a percentage by which future value dollars are reduced year to year to a present value. The commonly accepted discount rate is 15% and this value has also been used in the analysis given in this report (Thurston and Plum, 1991). Higher values for the discount rate are generally used in the oil and gas industry because of reservoir uncertainty and unpredictable circumstances that can lead to failure. The cost to produce or the breakeven price is defined as the minimum per unit price that would have to be charged by the developer to recover all direct costs, indirect costs, and a rate of return sufficient to compensate for depreciation, the time value of money, and the risk of failure. The developer would find this project economical if the calculated breakeven price

is lower than the market price. If the calculated breakeven price is higher than the market price, the project would not be economical. If the breakeven price of the hydraulic energy is lower than the breakeven price of the hydraulic energy is lower than the breakeven price of methane and geothermal development, the overall average breakeven price will be reduced and economic viability enhanced. This economic analysis of the hydraulic turbine does not include site, well, and electrical distribution costs and it is assumed that these costs have been charged to the development of methane and geothermal energy development.

The base year for the analysis is 1991. An inflation rate of 5.0% was used to inflate all costs and revenues before 1991 to 1991 values. Further, all capital and operating costs are escalated by after 1991 by 3.0% in addition to the 5% inflation rate to allow for a more conservative analysis and it is assumed that the per unit cost of electricity does not escalate. Other assumptions for this economic analysis includes that the developer can borrow 40% of the capital requirements at an interest rate of 11%, a working capital of \$20,000 will be required and the development and construction period takes 12 months. The analysis also assumes a 5 and 10 year well / reservoir life and a 5 year debt life. Equipment life is assumed to be 10 years and a 7 year straight line method of depreciation is used. A 500 kw hydraulic turbine unit is assumed to have an overall operating factor of 95% and hence about 4,161,000 kWL will be generated over a 1 year period. A cost of \$15,000 was assumed for the additional effort of labor, administration and overhead. Direct maintenance costs are assumed to be \$6,250 or 5% of this equipment value. Inhibitor costs are assumed to be \$5,000. Insurance costs to cover the additional value of equipment and labor will be purchased at \$5,000 and a general contingency of \$10,000 is assumed to cover all other unpredictable events. No post operating costs or revenues are assumed and the

equipment will be dismantled for salvage value. It is also assumed that the hydraulic energy equipment will not contribute to the cost of decommissioning the site and the plug and abandon costs of the well. This is based on the original assumption that this equipment will enhance a detract from the overall economic success of the entire development (from, Thurston and Plum, 1991). Results are presented in a breakeven price format for a 15% discount rate. The effect of shorter well life is shown in Table 7.

Two other economic analyses were performed by Thurston and Plum (1991) and these are given in Appendix 1. For the first analysis they assumed that the developer would typically have to pay the one time engineering and tooling costs and the breakeven cost was calculated to be \$0.46 kWh. For the second analyses, they assumed that the turbines would be available off the shelf to develop and the breakeven price was calculated to be \$0.030 kWh. Engineering and tooling costs are the largest percentage of the capital building and equipment, and as a result of this the breakeven price is most sensitive to the change in this value.

The results of the economic analyses suggest that any geopressured - geothermal project should consider the development of hydraulic energy whether or not off the shelf technology is available. If high pressure hydraulic turbines are developed in time, then the hydraulic energy would improve the economic viability of any geopressured - geothermal resource. It is estimated that adding conversion of hydraulic energy to an operating system recovering heat and methane could reduce the overall cost of electrical production by about 1.5 cents per kWh. This is not a viable stand alone system if the well costs are to be borne by the conversion of hydraulic energy alone.

TABLE 7
Effect of well life on breakeven cost

Well Life (Years)	Includes 1st Time Development Costs (Breakeven price/kWh)	Excludes 1st Time Development Costs (Calculated on well life)
3	\$0.115	\$0.068
5	0.073	0.045
10	0.047	0.030

BRINE PRODUCTION AS AN EXPLORATION TOOL FOR WATER DRIVE GAS RESERVOIRS

A paper on this subject was presented by Phillip L. Randolph of the Institute of Gas Technology, Chicago, Illinois, at the 17th Intersociety Energy Conversion Engineering Conference held at Los Angeles, California in August 8-13, 1982. In this paper Randolph presented data to demonstrate discovery of free natural gas by brine production from two "dry" wildcat wells which were tested under the DOE geopressured - geothermal "Wells of Opportunity" research program (Lear G.M. Koelemay Well No. 1 and the Riddle - Saldana Well No. 2). Concepts for the biogenic origin of natural gas, and the trapping of that gas in commercially producible reservoirs were also reviewed and it was suggested that as in the case of the two wells discussed, appropriate brine production tests may result in production of otherwise undiscoverable hydrocarbons. The information compiled here is taken directly from Randolph (1982).

Individual sandstone bodies contain widely varying relative amounts of total brine and total natural gas. Reasons for this include the variations in the processes of clay dehydration, generation of natural gas and vertical transport in fault planes. Gravity separation causes layering as seen in Figure 6, if the total quantity of natural gas in a sandstone body exceeds the amount soluble in the total brine content in the sandstone. A film of water is maintained by surface tension on the surfaces of the sand grains and its cementing material in the "gas cap" portion of the sandstone body, but the continuous mobile phase is gas which includes water vapor at the partial pressure determined by the temperature of 250° to 300°F. The amount of gas in place is about 100 SCF /ft³ of reservoir rock volume. The mobile fluid phase is brine with natural gas in solution, in the aquifer portion of the sandstone body. The amount of solution gas present is

about 1.0 SCF /ft³ of the reservoir rock. Both mobile gas and mobile brine phases are present in the "transition zone" Figure 6. The relative amounts at each depth are determined by the capillary pressure rise of water in the pores between sand grains and therefore the size distribution of these pores. In a very high permeability reservoir (100 - 1000 md); capillary forces may provide a transition zone only a foot or 80 thick. When the pore sizes are small (permeability about 1 millidarcy), the transition zone thickness may be ten feet. When the permeability is less than 1 md, the entire extent of the sandstone may be within the transition zone (Randolph, 1982).

The target of the gas industry is generally the high pressure gas cap of the sandstone bodies as illustrated in Figure 6. If production testing revealed mostly brine production, the well was abandoned as a "dry hole". As fluid pressure in a sandstone body reduced by gas production from "successful" wells, the compressibility of the brine and reservoir rock causes upward movement of the top of the transition zone. When this results in operating costs, including brine disposal, being in excess of revenue from gas sales, it becomes economically unprofitable and the producing interval is abandoned. In contrast to the industry "gas cap" production target, the DOE geopressured - geothermal research program evaluated energy production from geopressured aquifers that are not accompanied by gas caps or by transition zones within the same isolated sandstone body (Randolph, 1982).

Short duration tests on the Lear G.M. Koelemay Well No. 1 and Riddle Saldana Well No. 2, which were carried out under the DOE "Wells of Opportunity" Program, confirmed the existence of gas in excess of solubility in reservoir brine. In the Lear G.M. Koelemay Well No. 1 test, the horizontal pressure gradient from brine production resulted in coning of gas down to a well that penetrated the sandstone in the aquifer region. This well was then placed in commercial

Figure 6. - - Cross section of a geopressed sandstone reservoir (Randolph, 1982).

production. The Riddle Saldana Well No. 2 provided evidence of small free-gas accumulations that may have been from the "transition zone". The most striking feature of the tests from the Koelemay well was the increase in gas / brine ratio from 31 to over 37 SCF / STB during the first flow test. The other notable features of these tests was the high and increasing natural gas liquids (NGL) content of the flare line gas during the first flow test and the detection of produced oil in brine samples.

Several characteristics of the production from the Riddle Saldana Well No. 2 also suggested that the reservoir contained gas in excess of saturation in the brine. Included in these characteristics are (1) the reduction of bottomhole pressure from increasing the choke opening on November 21, 1980, was accompanied by an abrupt increase in produced gas / brine ratio. This is as expected for a reservoir containing gas at critical saturation near the wellbore (2) NGL contents of produced gas correlated with gas / brine ratio at the times of sample collection (3) the initial peak at a gas / brine ratio of almost 50 SCF / STB occurred immediately after bottoms-up. Careful review of prior well history showed no possibility that gas had accumulated near the wellbore from prior operations. No dry gas bearing strata were penetrated by the well and the total production from the sand prior to starting the test was less than 1000 barrels. This small amount of production of gas saturated brine could not possibly have released enough gas in the vicinity of the wellbore to provide the excess gas observed in this initial peak in gas / brine ratio. (4) Two bottomhole samples collected before the test, but after flowing the well with drawdown of only a few tens of psi to provide fresh reservoir brine, revealed gas / brine ratios of 38.7 and 38.8 SCF / STB. These values agreed very closely with the minimum in gas / brine ratio observed during the first full day of production.

The following two characteristics of the two wells tested are particularly relevant in as much as the other well tests illustrated conditions. Under which brine production testing may be a viable exploration tool.

- 1) The reservoirs were sufficiently geopressured for initial shut-in pressure on a brine filled wellbore to be more than 2500 psi.
- 2) Sandstone thickness and permeability were such that a production more than 1000 psi of drawdown of bottomhole pressure.

In the two cases of well tests examined, clear indications of gas in excess of solubility in reservoir brine were observed by the time cumulative production was a few thousand barrels. This amount of brine can be disposed of at modest cost. However, if the product of permeability times thickness were much greater, then drawdown sufficient to detect excess gas would require much higher flow rates and longer times. Testing costs would therefore be much higher if hundreds of thousands or millions of barrels of brine had to be produced.

Definitive onsite data collection and interpretation should be an essential part of testing with costs low enough to be commercially viable. The tests should include (1) brine analysis, such that expected gas solubility in brine corrected from salinity effects can be promptly defined, (2) onsite gas analysis to provide composition data to provide composition data essential to accurately interpret orifice meter data, (3) real-time determination of gas and brine production rates with a time resolution of ½ hour or less, and (4) computation procedures that include (a) correction of measured gas flow for water vapor passing through the orifice meter, (b) addition of gas remaining in solution in brine from the separator to gas observed from the separator, and © correction of measured brine flow rates for temperature and pressure at the turbine meter.

In general, the overall accuracy of on-site data collection and interpretation should provide resolution of better than 1 SCF / STB of brine. With such testing and resolution, the data from the DOE's "Wells of Opportunity" suggests that less than 24 hours of brine production with bottomhole pressure drawdown in excess of 1000 psi may well indicate whether a free gas phase exists in close proximity to the wellbore. If initial results are encouraging, additional testing will be required to define commercial potential (from, Randolph, 1982).

STUDY OF SUPERCRITICAL RANKINE CYCLES

A publication on this study entitled "The variable pressure supercritical Rankine cycle for integrated natural gas and power production from the geopressured - geothermal resource" was published in 1982 by the Geopressure Projects Office, Houston, Texas, authored by Fred L. Goldsberry, Director (NVO-240, DE82008937). The summary compilation provided below is taken directly from this report.

Full utilization of the geopressured - geothermal resource requires that the geothermal heat and the geopressure hydraulic energy be recovered. The study by Goldsberry (1982) describes the thermodynamic and operating restrictions which appear to favor the application of a variable pressure supercritical Rankine power cycle utilizing propane for the recovery of thermal energy from the geopressure - geothermal resource. The power cycle is also integrated into a natural gas recovery scheme that conserves reservoir pressure for brine disposal and produces gas at pipeline pressure.

There are several factors regarding the geopressured - geothermal resource which bound the parametric search for a thermal power cycle with hydraulic energy utilization, and a gas

recovery scheme. The brine temperature in the geopressure will in general be higher than 250°F (395°k) due to depth. Wells completed in the Tuscaloosa geopressured - geothermal fairway may have brine temperatures of about 450°F (505°k) and those in the Frio and Wilcox fairways are likely to have brine temperatures between 280° - 350°F (411°k - 444°k). Due to heating of the upper rock formations, the bottomhole fluid temperature will be asymptotically approached at the surface as the well is produced. At a production rate of 20,000 BPD, the brine surface flowing temperature will approach the bottomhole value by 10°F (5.5°k) within a few days. Therefore, any acceptable power plant design must be able to operate throughout the anticipated transient temperature range. A single portable plant design that can be used throughout the resource base area is most desirable and appears feasible. Scale formation and corrosion activity could be reduced or inhibited by rapid brine cooling. As CO₂ is an integral component of the solution gas, cooling prior to final pressure reduction will retain CO₂ in solution while slightly reducing methane solubility. The primary heat exchanger failing mechanism is the dissolution of CO₂ and subsequent carbonate scale formation. The CO₂ retained may provide the margin of safety in a pipeline gas specification to avoid acid gas removal entirely. Brine cooling prior to gas separation reduced the load on the gas dehydration plant.

An important factor that needs to be taken into consideration in the selection of the cooling tower/ambient heat exchanger is the brine cooling approach temperature. For the sake of disposal compatibility, there appears to be no reason for further cooling of the brine once it has been cooled to 150°F (340°k). By cooling the brine to 80°F (300°k), a carbonate precipitation problem could occur as the brine is reheated by the natural geothermal gradient in the disposal formation. Cooling below 150°F (340°k) can cause silica precipitation. Anticipated wellhead

pressures will range from 200 - 600 bar. Practical limitations to working pressures can be economically handled within current standard industry practices. The overall production schematic is shown in Figure 7. It demonstrates the integration of the supercritical power cycle into the natural gas processing system. Gas production will be the primary economic consideration requiring that power production be placed on a non-interference basis. The power production system must be capable of following the production transient of the well. The power plant will be electrically base loaded with its output determined by well production. Geopressured brine wells cannot be economically produced by basing well production upon power plant requirements. Power generation is clearly a second priority in resource production economics (from, Goldsberry, 1982).

In many cases, hydraulic energy recovery will not be considered as much of it will be used to produce the reservoir, and it would also be incremental to the installation of the thermal power generation system. Only one disposal well per production well will be required and the separator discharge pressure will be sufficient to dispose the produced fluids with no pumping being required. Conservation of pressure to minimize the horsepower for both gas compression and brine pumping will be necessary for the best utilization of the hydraulic energy which is also the first energy component to be depleted at a constant well flow rate. Further, the pressure recovery equipment must operate in an isolated manner from the rest of the production equipment to facilitate its early decommissioning at one site and application at another. Production maintenance during brine cooling is necessary to provide sufficient working pressure to control flow through the separator and to enter the disposal well. Production well spacings of three kilometers and single disposal well operations for each favor small air-cooled portable power

Figure 7. - - Geopressured - geothermal energy production (from, Goldsberry, 1982).

plants over the central station concept. Selection of a binary cycle is tied to oil and gas industry familiarity with gasoline and liquified petroleum gas production plants. These are operated as units of the same physical size contemplated for a single well geopressured - geothermal plant (from, Goldsberry, 1982).

For a power cycle specification, the cycle must first be selected and then a working fluid. Process conditions are then optimized for the cycle and the thermodynamic envelope in which it is to operate.

In selecting the power cycle its geometric compatibility with the heat source and sink must first be determined. The working fluid is selected in accord with the physical constraints imposed by the mechanics of the process. The temperature - entropy diagram (Figure 8) shows the resource and heat constraints. The work output of a power cycle is proportional to its area and the more fully a cycle fills the thermodynamic envelope, the more efficient will it be. The process designer must devise a thermodynamic cycle that will encompass the largest area within the resource thermal envelope to maximize work output. For a constant temperature heat source the rectangular shaped Carnot cycle discuses the theoretically most efficient means of power generation. When the heat source is a condensing vapor, like in the case of a steam dominated geothermal system, the Rankine cycle using a boiling fluid can be disposed to match the thermal characteristic of the resource. The supercritical Rankine cycle is the preferred power cycle for efficient exploitation of the geopressure - geothermal brine resource (from, Goldsberry, 1982).

A power cycle design can be described by constraints peculiar to the geopressured - geothermal resource and its production methodology. The heat source will be thermally subcooled brine at 225°F - 410°F (280°k to 480°k) containing large amounts (18,000 - 20,000

Figure 8. - - Power cycle matching to cooling and heating curves for the heat source and sink (from, Goldsberry, 1982).

ppm) of chloride and carbonate salts. Production rates will range from 5,000 to 40,000 bbl / day (.0092 - .0736 M³/sec). Well spacing will probably be no closer than three kilometers due to sand permeabilities of 0.1 to .2 darcies. Brine handling equipment will be designed to operate between 10 and 100 bar for reasons of equipment availability and operating conditions in natural gas pipelines. Separator pressures lower than 10 bar result in flashing of steam and increased production of CO₂ without appreciable recovery of natural gas. Maximum natural gas pipeline operating pressures will not exceed 100 bar.

The desirable characteristics for the selection of a working fluid are as follows:

- 1) Non-corrosive
- 2) Non-flammable
- 3) High molecular weight (minimum turbine size)
- 4) Non-toxic
- 5) Low cost - availability - storability
- 6) Compatibility with "off the shelf" equipment
- 7) High liquid density to minimize pumping costs
- 8) Low vapor pressure with respect to pressure and temperature operating range considerations

After a review of the required thermodynamic properties, propane appeared to fit within the range of thermodynamic constraints for the power cycle most effectively. The supercritical propane cycle can produce 37% more power at a 25% lower capital cost per unit output than an equivalent double boiling subcritical isobutane cycle operating from a common resource.

Variations in condenser conditions or brine temperature will not vary this relationship appreciably within the design limitations imposed by the geopressure geothermal resource. The complexities

introduced by a double boiling cycle are not economically offset by increased generating capacity over the single boiling Rankine cycle (from, Goldsberry, 1982).

The relative merits of each power cycle from Goldsberry (1982) is given below:

Subcritical Isobutane Cycle Advantages

1. Isobutane cycle operates at lower pressure resulting in lower equipment costs.
2. Inefficiencies in converting shaft work to pump work favor the isobutane cycle due to its lower pumping requirements.
3. The log mean temperature difference for the isobutane cycle is slightly greater for the same temperature approach differential. Boiling heat transfer offers advantages in reducing required heat transfer surface area.

Supercritical Propane Cycle Advantages

1. The supercritical propane cycle offers a better theoretical efficiency for utilizing heat from a "sensible heat" thermal resource such as geopressure derived brine.
2. The equipment to execute the supercritical cycle simpler in that the primary heat exchanger is an extended process feed heater (economizer). The two-phase heat exchanger, the mist extractor and the control system required in the isobutane system are eliminated.
3. The condenser for the subcritical isobutane system will have a larger capacity requirement than the comparable supercritical propane system and a desuper-heater with controls.

The equipment required for each of the cycle is schematically shown in Figure 9.

The supercritical cycle is superior to the double boiling cycle. The double inlet turbine is more expensive and more complicated to operate. The construction requirements for a double

Figure 9. - - Schematic illustrations showing the power cycle component comparison (from, Goldsberry, 1982).

boiling power plant is probably not suitable with a single well production scheme. A comparison of the power plant energy balance of the different cycles is shown in Table 8. Goldsberry (1982) provides a common basis economic comparison to illustrate the point that economic performance. The cost analysis (Table 9) given by Goldsberry (1982) compares the cycles on both a common energy balance basis and a common unit cost basis for capital equipment. The supercritical propane cycle will provide the operator with lower unit capitalization charges and a greater net cash flow.

The three features important to small scale plant economics are (1) the operation be unattended, (2) whenever possible, off the shelf/shop packaged components be used, and (3) plant portability and operating flexibility are important in producing a depletable resource. With these factors in mind, Goldsberry (1982) gives a single flow diagram to describe the proposed power conversion concept (Figure 10). In this design the facts that a geopressured - geothermal well operates in a transient mode throughout its life and that formulation of control set points have to be designed to enable the power plant to take full advantage of the thermal energy available in any given well, have been taken into consideration. The plant design incorporates a modular concept. Cost analysis indicates that working with portable skid mounted mass produced standard design plants instead of fixed power plants, will result in significant cost reductions for new plants and maintenance. A higher salvage or residual value will also result for the plant at the time of reservoir depletion. Details of system operations are provided by Goldsberry (1982) who also has given a sample calculation form (Table 10) that can be utilized to evaluate a brine resource.

The principal unknown involved in the operations of a power plant utilizing brine from a geopressured - geothermal well are scaling and corrosion control within the brine propane heat

TABLE 8

POWER PLANT ENERGY BALANCE

POWER CYCLE:	SUPERCRITICAL PROPANE	SUBCRITICAL SINGLE BOILING ISOBUTANE	SUBCRITICAL DOUBLE BOILING ISOBUTANE
	(KW)	(KW)	(KW)
GENERATOR OUTPUT:	591	359	415
PUMP POWER:	(117)	(29)	(45)
CONDENSER FAN POWER:	(47)	(50)	(50)
AUXILIARY POWER:	(30)	(30)	(30)
NET POWER:	397	250	290
THERMAL EFFICIENCY:	9.0%	5.6%	6.6%

BRINE HEAT SOURCE: 4396.2 KWT(15,000,000 BTU/HR.)

CARNOT THERMAL EFFICIENCY: 17.6%

TURBINE EFFICIENCY: 80%

GENERATOR & WINDAGE LOSSES: 10%

ELECTRIC MOTOR EFFICIENCY: 92%

POSITIVE DISPLACEMENT FEED PUMP MECHANICAL EFFICIENCY: 95%

(from, Goldsberry, 1982)

TABLE 9

**COMMON BASIS
POWER PLANT COST ESTIMATES**

CAPITAL EQUIPMENT ITEM	SUPERCRITICAL PROPANE CYCLE	SUBCRITICAL SINGLE BOILING ISOBUTANE CYCLE	SUBCRITICAL DOUBLE BOILING ISOBUTANE CYCLE
	(\$K)	(\$K)	(\$K)
A/C CONDENSER	170	182	174
J/L HEAT EXCH.	190	83	95
BOILER	-	69	90
FEED PUMP	70	16	26
TURBINE-GEN.	236	195	250
SKID FAB.	120	120	135
FIELD ERECTION	60	60	60
TOTAL	846	725	830
UNIT COST (\$/KW)	2,131	2,900	2,862

(from, Goldsberry, 1982)

Figure 10. - - Supercritical power cycle with control scheme (from, Goldsberry, 1982)

TABLE 10

ESTIMATED GEOPRESSURED GEOTHERMAL BRINE
RECOVERABLE ENERGY CONTENT CALCULATION

NATURAL GAS ENERGY KW-HR/BBL

$$.0001 \times \frac{\text{GWR}}{\text{GWR}} \times \frac{\text{HHV}}{\text{HHV}} = \underline{\hspace{2cm}}$$

HEAT RATE - 10,000 BTU/KW-HR

THERMAL ENERGY

$$.0089 \times \frac{\gamma}{\gamma} \times \frac{C_p}{C_p} \times \frac{W}{W} \times \left(\frac{T}{T} - 175.0 \right) = \underline{\hspace{2cm}}$$

THERMAL EFFICIENCY - 9%

HYDRAULIC ENERGY

$$.000238 \times \frac{\Delta P}{\Delta P} = \underline{\hspace{2cm}}$$

EXPANDER EFFICIENCY - 85% GENERATOR EFFICIENCY - 92%

TOTAL ENERGY RECOVERABLE =

- GWR - GAS RECOVERED FROM SEPARATOR (SCF/BBL)
- HHV - HIGHER HEATING VALUE (BTU/SCF)
- γ - BRINE SPECIFIC GRAVITY (DIMENSIONLESS)
- C_p - SPECIFIC HEAT (BTU/LBM-°F)
- W - DIMENSIONLESS WORK FUNCTION FOR VARIABLE
PRESSURE SUPERCRITICAL PROPANE CYCLE
- T - FLOWING WELLHEAD TEMPERATURE (° F)
- ΔP - FLOWING DIFFERENTIAL PRESSURE ACROSS CHOKE (PSIG)

(from, Goldsberry, 1982)

exchanger, operating manpower, and periodic preventive maintenance requirements.

Confirmation of component performance and reliability will reduce the perceived high risk of long term capital commitments to the production of the resource. Operating experience can be gained to support equitable rule making by regulatory bodies (from, Goldsberry, 1982).

APPLICATION OF THE GEOPRESSURED-GEOTHERMAL RESOURCE TO PYROLYTIC CONVERSION OR DECOMPOSITION/DETOXIFICATION PROCESSES

This summary was compiled directly from the following publication:

Propp, A.W., A.E. Grey, J. Negus-de Wys, M.M. Plum, D.R. Haefner, 1991, Feasibility study: Application of the geopressured - geothermal resource to pyrolytic conversion or decomposition/detoxification processes: Idaho National Engineering Laboratory, EG&G, Idaho, Report No. EGG-EP-9842, DOE Contract No. DE-AC07-76ID01570, 79 p. + Appendix.

This study presents a preliminary evaluation of the technical and economic feasibility of selected conceptual processes for pyrolytic conversion of organic feedstocks or the decomposition/detoxification of hazardous wastes by coupling the process to the geopressured-geothermal resource. The report presents a detailed discussion of the resource and of each process selected for evaluation including the technical evaluation of each. A separate section presents the economic methodology used and the evaluation of the technically viable process. A final section presents conclusions and recommendations.

The objective of this study is to investigate the utilization of the geopressured-geothermal resource as the energy source for conceptual processes for either pyrolytic conversion of organic feedstocks or the decomposition/detoxification of hazardous wastes. Thus, a brief description of

the resource follows by way of introduction.

The geopressed-geothermal resource has an estimated 5700 quadrillion Btus (quads) (6.0×10^{21} J) of gas and 11,000 quads (12×10^{21} J) of recoverable energy in the onshore Texas and Louisiana Gulf Coast area alone. This large energy potential provides the impetus for coupling the resource to processes such as the ones conceptualized in this report. These resources have three energy forms: thermal, hydraulic, and chemical (methane gas), all of which could be utilized in the proposed processes.

Currently, three wells have been identified as possible sources to be used in future site demonstrations of the processes. These are the Gladys McCall Well in Cameron Parish, Louisiana; the Pleasant Bayou Well in Brazoria County, Texas; and the Hulin Well in Vermilion Parish, Louisiana. Table 11 provides a summary of well characteristics taken from Negus-de Wys and Dorfman (1990). The data have been adapted by converting units as appropriate for the proposed processes. The maximum flow rates range from 438 gpm (33.2 L/s) for Hulin to 1167 gpm (88.42 L/s) for Gladys McCall. The flowing wellhead pressures and temperatures range from 2000 psia (13.8 MPa) at 268°F (131°C) for Gladys McCall to 3500 psia (24.1 MPa) at 330°F (166°C) for Hulin.

Finally, the total dissolved solids (TDS) content of the brine ranges from 95,000 mg/L (0.79 lb/gal) for Gladys McCall to 195,000 mg/L (1.63 lb/gal) for Hulin.

A brief discussion of each of the selected processes is presented below followed by a discussion of other high temperature/high pressure treatment alternatives.

TABLE 11

Resource description

	Gladys McCall	Pleasant Bayou	Hulin
Maximum Flow Rate (gpm)	1167	729	438
Flowing Wellhead Pressure (psia)	2000	3000	3500
Bottomhole Temperature (°F)	298	302	360
Flowing Wellhead Temperature (°F)	268	292	330
Gas/Water Ratio (scf/gal)	0.64	0.57	0.81
Methane (% of Gas)	85	85	93
CO ₂ (% of Gas)	9.7	10	4
Estimated Reservoir Size (billion gal)	168	336	588
Total Dissolved solids (mg/L)	95,000	127,000	195,000
Total chlorides (mg/L)	57,000	70,000	115,000

(from, Propp et.al., 1991)

Pyrolytic Conversion

Pyrolysis of organic wastes could provide two benefits: (a) the reduction of organic waste, and (b) the formation of hydrocarbon compounds.

Oil company laboratories have worked with pyrolysis for the past 15 years with Shell Oil, Exxon, Chevron, and Amoco being among the pioneers in this field. The natural feedstocks for hydrocarbon source materials are marine and terrestrial organic material (kerogen).

With geological time and temperature these source materials are converted to oil and gas. The ingredients are basically "cooked" under pressure. Thus, in proprietary oil company laboratories researchers use high pressure autoclaves, first replicating closed systems, and more recently, semi-open systems.

In the proposed application, processing would be at geopressured - geothermal reservoir conditions or above, if higher conditions would be required to promote conversion rates. Higher temperatures and pressures could be achieved by also utilizing the hydraulic and chemical energy in the geopressured resource. One possibility in processing could be either by direct contact with reservoir fluid or by circulating fluid down into the reservoir to generate conditions. Experimental feedstocks previously considered for processing include biomass or derived products such as wood chips, straw, bagasse (residual from cane processing), water hyacinths, agriculture processing residues, cellulose, hemicellulose or lignin, RDF, peat and organic sludge. The specific feedstocks selected would depend upon the goal of the pyrolysis and such variables as availability, cost and processing site location in order to optimize process economics. Similarly, process specifics would depend on reservoir conditions, location and product selection. These details would be finalized during final design to optimize the overall process and economics.

In summary, the pyrolysis process has been included in considering the use of supercritical water in the detoxification of pollutants for three basic reasons: (a) process conditions for pyrolysis can be similar to supercritical conditions, (b) it addresses two concerns, reduction of waste and development of hydrocarbons and (c) pyrolysis may be more compatible with the geopressured resource as a process to utilize the resource.

Supercritical Water Oxidation (SCWO)

Supercritical water destruction of hazardous organic wastes could provide five major benefits: (a) the reduction of organic waste, (b) the potential for high destruction efficiencies, (c) the production of clean effluents containing no hazardous constituents, (d) a readily available means for disposing of inorganic products formed during the destruction and (e) applicability to a wide variety of wastes.

Above its critical point water exhibits properties that make it eminently suitable as a medium for destruction of most organic compounds. The high dielectric constant of liquid water (80), ascribable to the hydrogen bonding present in the liquid, decreases to about 2.5 with the concomitant weakening and disappearance of hydrogen bonding. In addition, there is a corresponding decrease in fluid density from 1 g/cm³ (62.4 lb/ft³) to about 0.3 g/cm³ (19 lb/ft³). The net result of these two effects is a pronounced change in the solvent properties of water. As the critical point is approached there is a sharp decrease in solubility of inorganic compounds with a corresponding sharp increase in solubility of organic compounds and nonpolar gases; supercritical water is a poor solvent for inorganics and a good solvent for organics.

In addition to its solvent properties, supercritical water also exhibits the surface tension,

viscosity, and diffusivity behavior typical of supercritical fluids. This makes possible rapid mixing of constituents in a single phase without use of mechanical stirring or agitation. Furthermore, reaction kinetics are not diffusion limited.

The proposed process has potential applicability to a wide variety of wastes containing organic constituents. It would be particularly appropriate for aqueous media such as wastewater or groundwater contaminated with organics. In addition, it could be applied to liquids, slurries, sludges, or solids. The latter could be in the form of solid organics or solids contaminated with organics.

In the proposed application, processing would occur at or above supercritical conditions for water. These conditions are not directly available from the geopressured-geothermal resource. Typical wellhead conditions are about 150°C (302°F) and 204 atm (3000 psia or 20.7 MPa), corresponding to slightly less than critical pressure but well below critical temperature. The methane or other combustible gas present in the brine would be burned, utilizing the heat released to raise the fluid temperature above the critical point. Waste and compressed air or oxygen would be injected into the supercritical water where the organics would be rapidly oxidized. Residence times for complete destruction are typically on the order of 1 min or less. With 2% or more of combustible waste, the reaction should become self-sustaining. Because of the high rate of the combustion process, operation approaches adiabatic conditions, with heat losses being small. For example, if compressed air is used as the oxidizer and the feed contains about 5 wt% of organics with an inlet temperature of 400°C (752°F) at about 250 atm (3670 psia or 25.3 MPa), fluid outlet temperatures from the reactor on the order of 500 to 600° (932 to 1110°F) should be attainable. Temperature at reactor outlet will depend upon specific inlet conditions and

concentration of organics in the feed.

Under the operating conditions above, reaction of most organics should be essentially complete, with the primary reaction products being carbon dioxide and water. Although this oxidation is similar to combustion, the formation of nitrogen oxides should be negligible because of the much lower temperatures involved, in contrast to those typical of incineration (1800°C; 3300°F). In addition, any inorganics present would precipitate out under these conditions and could be separated out by use of a hydrocyclone, for example.

If necessary, part of the effluent fluid from the process could be recycled for use as the reaction medium to maintain the process. Part of it would be blown down to prevent excess solids buildup in the system. The blowdown could be reinjected into the reservoir, if appropriate, or be cooled to ambient conditions for recovery and disposal of the solids. Energy from the blowdown would be recovered to preheat the makeup fluid from the reservoir. At reactor outlet conditions, after removing precipitated solids, the fluid would be a mixture of relatively pure superheated steam and carbon dioxide. A portion of this fluid could be bled off to provide energy for operating the system air compressor turbine, either directly or by heat exchange to another working fluid. Energy from the effluent could also be recovered by heat exchange to preheat the makeup fluid, air and waste. The methane from the makeup brine would be used to provide additional energy.

Process specifics will depend on actual reservoir conditions and waste feed composition. These details would be finalized during detailed process design to optimize the overall process and economics.

In summary, it is expected that application of the geopressured-geothermal resource to the

supercritical water destruction of organic wastes will reduce process energy costs and provide a convenient means of disposing of inorganic constituents from the process.

Other High Temperature/High Pressure Processes

The only other high temperature/high pressure process comparable to the supercritical water oxidation (SCWO) process being considered is wet air oxidation (WAO). In point of fact, it will be seen that SCWO is actually an extension of the WAO process to higher temperatures and pressures to capitalize on the advantages of operating at SCF conditions. WAO is applicable for situations involving relatively innocuous wastes where the intent is to reduce chemical oxygen demand (COD) before discharge, e.g., to the sewer, without the need for extremely high destruction removal efficiencies (DREs). However, WAO suffers from several limitations that make it inapplicable to the destruction of the majority of hazardous organic wastes.

In the first place, under the conditions of operation, the solubility of oxygen in water is significantly less than the stoichiometric amount needed for complete oxidation. Therefore, a two-phase mixture exists in the reactor, producing residence-time requirements ranging from 0.5 to 2 h. Because the reactor not only must operate at high temperatures and pressures but must also be of relatively large volume to meet the residence-time requirements, the associated high cost will have a significant impact on the capital costs for the process.

Secondly, DREs depend not only on operating conditions but also on the relative stability of the constituents of the waste. For WAO, DREs typically range from 50 to 95% depending upon conditions. The DREs for less stable organics such as nitrotoluenes and nitrobenzenes can be as high as 99.9%; however, for more refractory classes of compounds, such as polychlorinated

biphenyls (PCBs), DREs are much lower and would not meet regulatory requirements. Thus, the applicability of WAO is much more restricted compared to the range of wastes treatable by SCWO. Finally, because WAO does not completely convert the waste constituents to innocuous products, the process effluent streams, including both liquid and off-gas, can contain appreciable levels of organics requiring additional treatment before the effluent streams can be discharged to the environment.

Selection of processes for evaluation in this study has been based both on processing potential as well as the applicability of coupling the process to the geopressured-geothermal resource. Thus, the two processes selected, pyrolytic conversion and decomposition /detoxification processes, both have significant processing potential. For these processes, there are a variety of abundant feedstocks. Substances treated by supercritical water oxidation are listed in Table 12. Also, the feedstocks are widely enough distributed geographically so that access to the resource will not be restricted. In addition, the processes are such that the energy available in the resource, thermal, hydraulic, and methane gas, can be effectively utilized to at least partially offset process energy requirements.

Technical Evaluation

The selected processes have been evaluated on the basis of technical feasibility from both the scientific and engineering level. First, the scientific viability of the respective process has been evaluated to establish operational parameters, limitations, weaknesses, and restrictions, followed by an evaluation of the engineering viability of each process, looking at the same types of information used to evaluate scientific viability.

TABLE 12

Substances treated by supercritical water oxidation (SCWO).

Organic
Chemical

Aroclors (PCBs)
Benzene
Biphenyl
Carbon tetrachloride
Carboxylic acids
Chlorinated dibenzo-p-dioxins
6-chloro-2,3,4,5-tetrahydro-
3-methyl-1H-3-benzazepine
hydrochloride
Chlorobenzene
Chloroform
2-Chlorophenol
Chlorotoluene
o-Chlorotoluene
Coal
Cyclohexane
DDT
Decachlorobiphenyl
Dextrose
Dibenzofurans
Dibutyl phosphate
Dichloroacetic acid
Dichloroanisole
Dichlorobenzene
Dichlorobiphenyl
4,4'-Dichlorodiphenyl
Dichloroethylene
Dichlorophenol
Dimethyl sulfoxide
Dimethylformamide
Dinitrotoluene
Ethanol
Ethyl acetate
Ethylene chlorohydrin
Ethylene glycol
Ethylenediamine tetraacetic
acid
Fluorescein
Hexachlorobenzene
Hexachlorocyclohexane
Hexachlorocyclopentadiene
Hexachlorocyclohexane
Isopropanol

Mercaptans
Methanol
Methyl cellosolve
Methylene chloride
Methyl ethyl ketone (MEK)
Nitrobenzene
Octachlorostyrene
Pentachlorobenzene
Pentachlorobenzonitrile
Pentachloropyridine
Surfactants
Tetrachlorobenzene
Tetrachloroethylene
Tetrapropylene
Tributyl phosphate
Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Trichlorophenol
Trifluoroacetic acid
Transformer oil
Urea
Xylenes

Biological Substances

Bacillus Stearothermophilus
(Heat resistant spore)
Carbohydrate
Cellulose
E. Coli
Endotoxin (pyrogen)
Human waste
Malaria antigen
Paper
Protein
Sulfolobus Acidocalda
Yeast

Inorganic
Chemical

Alumina
Ammonia
Ammonium chloride
Ammonium sulfate
Boric acid
Calcium carbonate
Calcium chloride
Calcium oxide
Calcium phosphate
Calcium sulfate
Cyanide
Heavy metal oxides
Hydrochloric acid
Iron
Iron oxide
Lithium sulfate
Magnesium oxide
Magnesium phosphate
Magnesium sulfate
Potassium bicarbonate
Potassium carbonate
Potassium chloride
Potassium sulfate
Silica
Sodium carbonate
Sodium chloride
Sodium hydroxide
Sodium nitrate
Sodium sulfate
Soil
Sulfur, elemental
Titanium dioxide

(from, Propp et.al., 1991)

As stated previously, the proprietary nature of the SCW0 technology currently available precluded obtaining definitive process information from vendors. Thus, the schematic process flow diagram, Figure 11, is conceptual in nature, lacking the higher level of specifics required for detailed process design and optimization. In addition, the process simulation was idealized, not taking into account in detail all of the process losses such as heat loss from the reactor. The process parameters used to develop the design case are summarized in Table 13. Development of a detailed process design will require, in addition to specifics on actual reservoir conditions and waste feed composition, close collaboration with vendors which was beyond the scope of this study.

Conceptually, the SCW0 process coupled to the geopressured-geothermal resource provides an attractive means of destroying hazardous organic waste to produce environmentally benign effluents while utilizing the energy of the resource to offset the energy requirements of the destruction process. In point of fact, as discussed previously, energy in excess of process input requirements can be produced. If this energy, equivalent to about 2.0 MWe (2680 hp) is recovered as electricity and sold, additional revenues would be generated to offset processing costs. This would reduce disposal costs, making the process more attractive economically as an alternative disposal technology.

In an energy balance for a facility using air as the oxidizing agent (Table 14), by far the largest energy consumption in the process is the requirement for the air compressor. The compressor accounts for 7100 hp (5.3 MWe), corresponding to 96% of the work input. Significant savings in compressor energy requirements can be achieved by using an oxygen enriched oxidizing medium, as shown in Table 15 for 99% oxygen as the oxidizer. Under these

STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
PRESSURE (PSIA)	14.7	3000	14.7	3700	3700	3700	3700	3700	40	3600	3600	10000
TEMPERATURE (°F)	70	300	70	1100	1100	1100	2785	1200	270	300	70	145
FLOW (LB/HR)	3055	30100	46200	3055	30100	46200	75215	75215	75215	4140	14725	18865

Figure 11. - - Conceptual process flow diagram: decomposition/detoxification process for 1000,000 GPD (455,000) L/d). (from, Propp, et.al., 1991).

TABLE 13

Process parameters for SCWO.

Reactor Inlet Temperature: 594°C (1100°F)
Reactor Pressure: 251.8 atm (3700 psia or 25.51 MPa)
Organic Concentration: 10 wt% (Range: 2 to 20 wt%)
Feed Heating Value: 1800 Btu/lb (4190 kJ/kg)
(Range: 350 to 3600 Btu/lb or
810 kJ/kg to 8400 kJ/kg)
Reactor Residence Time: ~1 min
Destruction Removal Efficiency (DRE): ≥ 99.999%
Oxidant: Air or Oxygen @ ~10% excess
Flow Rate: 100,000 gpd (455,000 L/d)

(from, Propp et.al., 1991)

TABLE 14

Energy balance for a 100,000 GPD (455,000 L/d) processing plant utilizing air as the oxidizing medium.

ENERGY INPUTS		
	<u>W (hp)</u>	<u>Q (MBtu/hr)</u>
Waste (pump, heat exchange)	17.6	1.95
Air (compressor, heat exchange)	7100.0	9.15
Brine (pump, heat exchange)	33.7	39.05
Quench water (pump)	72.5	--
<u>Brine return (pump)</u>	<u>177.5</u>	<u>--</u>
TOTAL	7401.3	50.15

ENERGY OUTPUTS		
	<u>W (hp)</u>	<u>Q (MBtu/hr)</u>
Hot exhaust (turbine, heat exchange)	10,130	49.75
<u>Slurry (heat exchange)</u>	<u>--</u>	<u>5.60</u>
TOTAL	10,130	55.35

(from, Propp et.al., 1991)

TABLE 15
Energy balance for a 100,000 GPD (455,000 L/d) processing
plant utilizing 99% oxygen as the oxidizing medium.

ENERGY INPUTS		
	<u>W (hp)</u>	<u>Q (MBtu/hr)</u>
Waste (pump, heat exchange)	17.6	1.95
Oxygen (compressor, heat exchange)	1500.0	2.06
Brine (pump, heat exchange)	33.7	39.05
Quench water (pump)	72.5	--
<u>Brine return (pump)</u>	<u>177.5</u>	<u>--</u>
TOTAL	1801.3	43.06

ENERGY OUTPUTS		
	<u>W (hp)</u>	<u>Q (MBtu/hr)</u>
Hot exhaust (turbine, heat exchange)	6780.0	48.45
<u>Slurry (heat exchange)</u>	<u>--</u>	<u>9.40</u>
TOTAL	6780.0	57.85

(from, Propp et.al., 1991)

conditions compressor requirements drop drastically to only 1500 hp (1.1 MWe). In this scenario, the excess output from the turbine increases to almost 4980 hp (3.7 MWe), providing additional electrical power.

Since air is composed of over 78% nitrogen by volume, an additional advantage of using an oxygen enriched oxidizing medium will be a reduction in the size required for the reactor, which is one of the major capital costs for the facility. However, the reduction in cost of the reactor will be more than offset by the cost of an enrichment facility or, as an alternative, the rental of a facility to store and handle liquid oxygen.

Direct energy recovery has been used for this conceptual process because it will be the most energy efficient as well as being potentially the most economical from a capital equipment standpoint. The final viability of this particular option would be determined during the later detailed design phase if proceeding with a demonstration of this application of SCWO coupled with the geopressured-geothermal resource was pursued.

There is an alternate option for recovering energy from the process effluent. In this option, heat would be exchanged from the SCWO reactor effluent to a secondary fluid that would be used to power a turbine. The secondary fluid could be water operating in a closed loop. This option would require higher capital equipment costs and produce lower energy recovery efficiencies. For these reasons, the use of direct energy recovery was considered as preferable for the economic analysis that follows.

In summary, the scientific viability of the proposed process has been established. There are issues associated with the engineering feasibility, but there are options that will allow these issues to be resolved. Thus, overall the process of coupling SCWO to the

geopressure-geothermal resource has been evaluated as being technically feasible.

This is the only process that was evaluated to be technically viable, an economic evaluation was performed to determine capital, operating and other costs associated with the process to determine commercial viability.

Assuming a very conservative discount rate of 26%, the breakeven price to develop a viable geopressured-geothermal/scwo facility is \$0.060/kWh and \$2.85/gal (\$0.627/L), both prices higher than currently acceptable market levels found in the assumed Gulf Coast location. When current market prices of \$0.020/kWh and \$1.20/gal (\$0.264/L) (average) are assumed, the discount period is greater than ten years and the NPV is greater than a negative \$6,000,000, a net loss of capital to investors (Table 16).

Economically, the most sensitive variable to the development and use of this technology is risk, a result of technical and engineering uncertainty. Because of the uncertainty, we had to assume a 4 year leadtime before production begins. Because of unproven engineering and operating data, a high discount rate of 26% is used, reducing any revenue stream by 50% within 4 years. Because little or no vendor data is available to calculate an installed plant cost, conservative 10 and 20% contingency factors is assumed. When all of these risk factors are compounded, the total risk overwhelms even the best of cash flows.

When uncertain variables become less uncertain, risk drops, the discount rate drops, contingency factors drop, and breakeven prices drop; project viability increases. Assuming additional research, engineering study, and analysis would increase the knowledge base and substantially reduce the variance of the variables, we would expect breakeven prices to fall.

TABLE 16

Breakeven cost for three selected levels of uncertainty.

	Breakeven	Discounted Payback in years	NPV in 000's
26% discount: 20% const cont 10% oper cont 90% cap factor 5 y lead time	\$0.060/KWh \$2.85/gal	10.0	<\$12.5
current market analysis as above	\$0.020/KWh \$1.20/gal	10.0	<\$6,122.0>
21% discount: 15% const cont 7.5% oper cont 92.5% cap factor 5 y lead time \$0.045/KWh \$2.25/gal 9.7 \$151.0	\$0.045/KWh \$2.25/gal	9.7	\$151.0
15% discount: 10% const cont 5% oper cont 95% cap factor 1 y lead time	\$0.030/KWh \$1.38/gal	9.9	\$181.0

(from, Propp et.al., 1991)

CONCLUSIONS

In keeping with the stated goal of the DOE Geopressured-Geothermal Research Program to investigate various applications with the potential for recovering process energy from the three forms of energy contained in the resource, i.e., thermal, hydraulic, and methane gas, this study considers three different high-temperature/high-pressure processes that could potentially be coupled with the resource. The three processes are: a) wet air oxidation (WAO), b) pyrolytic conversion and c) decomposition/detoxification of hazardous waste by SCWO. The conclusions regarding each process are presented separately.

Wet Air Oxidation (WAO)

Development of WAO is not considered feasible because of technical limitations related to long reactor residence times and unacceptable destruction efficiencies, typically in the range of only 50 to 95%.

Pyrolytic Conversion

Development of pyrolytic conversion is not considered technically or economically feasible because of limitations related to long reactor residence times and difficulties in feeding some feedstocks that significantly limit throughput. In addition, there are other economic disadvantages because the product of such a process is typically a complex mixture requiring significant further processing before an economic product is obtained.

Decomposition/Detoxification Process

There is a significant processing potential for this process within the vicinity of the resource, minimizing transportation costs as a significant factor in the economics. Feedstocks would consist of organic liquids, oils, and sludges.

Processing would occur at SCF conditions, which are above those available directly from the resource. However, the SCWO process would produce more energy than it consumed, providing the potential for additional revenues from the sale of electricity.

For the conceptual, SCWO process studied, the reactor would operate at 1100°F (594°C) and 3700 psia (251.8 atm or 25.51 MPa) producing rapid, essentially complete oxidation of the organic components present in the fluid. Thus, DREs of 99.999% or higher could be achieved at reactor residence times of 1 minute or less, producing process effluents that would be environmentally innocuous. This gives the SCWO process major advantages over other destruction technologies.

Direct recovery of the excess energy from the process is the most efficient option; however, the required turbine technology is not yet commercially available. Because of the limited market potential, it would not be cost-effective to develop a new turbine design only for this application. Heat exchange to a secondary working fluid coupled to a turbine would be another, less energy efficient option for energy recovery. However, at this time use of a binary cycle system is probably the most realistic design.

Coupling of the SCWO process to the resource is definitely feasible but has not been successfully demonstrated. The capability of the SCWO process to handle the high salt levels present in the brine has not been successfully demonstrated. Under SCF conditions the inorganic

salts will be insoluble and precipitate out. Solids separation and removal in the reactor has not been successfully demonstrated at this level of solids loading and development work in this area would be required.

Millions of barrels of hydrocarbon, liquid, hazardous waste continues to be disposed of by convenient but environmentally unacceptable methods. The SCWO process is a potentially environmentally benign alternative to the present methods. Additionally, energy could be recovered in large enough quantities to provide cost efficient electrical power. The proposed technology shows tremendous promise of contributing to solving this nation's pollution and energy problems. However, although development of a geopressured-geothermal resource to dispose of these wastes and produce power may prove to be economically viable, analysis suggest that it is uneconomical at this time, primarily because of the undefined technical requirements, capital cost, and operating parameters and the conservative assumptions in analysis.

Results of the economic analysis done for this study are provided in Appendix 2 of this compilation.

CO-LOCATION OF MEDIUM TO HEAVY OIL RESERVOIRS WITH GEOPRESSURED - GEOTHERMAL RESOURCES AND THE FEASIBILITY OF OIL RECOVERY USING GEOPRESSURED - GEOTHERMAL FLUIDS

With U.S. oil imports approaching 50% of total consumption, creative methods of oil recovery that can maximize domestic resources become increasingly important. The U.S. has large deposits of heavy oil remaining in the ground, but it is too viscous to be recovered by conventional means. Thermal treatment of medium to heavy oils i.e. heating the oil in the

reservoir to make it easier to flow, can help make these deposits recoverable. Heavy oil recovered by this technology currently contributes about 7% to the total U.S. production. The application of geopressured - geothermal fluids to thermal enhanced oil recovery (TEOR) offers further advantages as in many instances the geopressured - geothermal resources are located near heavy oil deposits. This co-location of the resource with heavy oil reservoir makes it possible to profit from these advantages. Conventional TEOR methods such as hot-water flooding or cyclic steam injection act by increasing the temperature of the reservoir, thus lowering the viscosity of the oil. TEOR can convert heavy crude oil with a thick consistency to a liquid that can be pumped to the surface. These technologies, however, require pollution-generating gas or oil-fired heat sources, as well as large amounts of fresh water not available in arid regions.

Treatment of medium-to-heavy oil reservoirs with geopressured-geothermal brine has the potential to improve recovery without the disadvantages of conventional TEOR technology. It serves as an economical source of high temperature water for thermal treatment, eliminating the need for a fresh water source for steam and eliminating emissions from the burning of crude oil to provide a heat source. The geopressured - geothermal fluids under high pressure in the parent reservoir, when linked by suitable piping to an oil reservoir located at a shallower depth, can provide a self-propelled method of heat transfer to the target reservoir. The brine can heat the reservoir as in conventional TEOR, reducing the residual oil saturation and lowering the viscosity of the oil so that it can be moved more easily and in greater amounts. (From, Geopressured - Geothermal energy, the untapped resource - DOE brochure).

The U.S. Bureau of Mines published information circular No. 8263 in 1965 (Dietzman et al, 1965) which documented geographic locations of those reservoirs (Figure 12). Co-location

Figure 12. - - Geographic locations of heavy oil fields in the United States (from, Dietzman et al., 1965).

studies of medium to heavy oil with geopressured - geothermal resources in Louisiana were carried out by the Louisiana Geological Survey, Louisiana State University, Baton Rouge, Louisiana and similar studies in Texas were done by the Bureau of Economic Geology, University of Texas at Austin. Detailed results of these studies in Louisiana by John (1992) were published in the Louisiana Geological Survey Annual report for 1991 (C.G. Groat, Program Co-ordinator) titled "Technical Support for Geopressured - Geothermal Well Activities in Louisiana". The Louisiana co-location studies were performed under DOE Contract No. DE-FC07-85NV10425. The Texas study results by Seni et al (1992) were presented in their 1991 annual report titled "Consolidation of Geologic Studies of Geopressured - Geothermal resources in Texas: Co-location of heavy oil and geothermal resources in South Texas". These studies were carried out under a DOE Contract No. DE-FC07-85NV10412.

A summary of the Texas studies authored by Seni and Walter (1993) was published by the Bureau of Economic Geology, University of Texas at Austin, as Geologic Circular 93-3 titled "Geothermal and heavy-oil resources in Texas: direct use of geothermal fluids to enhance recovery of heavy oil". A comprehensive publication titled "The Feasibility of recovering medium to heavy oil using geopressured - geothermal fluids" authored by J. Negus de-Wys, C.E. Kinmel, G.F. Hart and M.M. Plum was put out by the EGG, Idaho, (Idaho National Engineering Laboratory), Report No. EGG-EP-9840 (1991). This work was performed under DOE Contract No. DE-AC07-76ID01570. The information compiled here below is taken directly from the aforementioned reports.

Ninety percent (90%) of the reservoirs in Louisiana have a gravity of $> 30^{\circ}\text{API}$. This still leaves a considerable number of producing fields with geopressured - geothermal tertiary

enhanced oil recovery (GP/GT TEOR) could be economical. Northern Louisiana contains more than 30 reservoirs that stratigraphically trap oil with a gravity of $< 25^{\circ}\text{API}$ mostly at depths of $< 3,000$ ft. However GP/GT reservoirs are not present in north Louisiana. Analyses of the data base from the Louisiana Office of Conservation indicated a large number of specific sites which test as bitumens ($0 - 8^{\circ}\text{API}$), heavy oils ($8 - 20^{\circ}\text{API}$) and medium oils ($20 - 25^{\circ}\text{API}$). In the southwestern part of Louisiana there are many reservoirs containing oils with a gravity of $< 25^{\circ}\text{API}$. The target reservoirs are sandstones of the Tertiary Period and many are water drives. A table listing the Louisiana Oil fields with $< 25^{\circ}\text{API}$ gravity oil production compiled from the last published Louisiana Department of Natural Resources Report (1979) is presented in the Louisiana Geological Survey Annual Report for 1991 (John, 1992). Later information on the medium to heavy oil occurrences is found in the oil and gas computerized information on production and well data files called the "PARS" system, maintained at the Louisiana Office of Conservation, located in Baton Rouge, Louisiana. This information was used to make a series of maps of southeast and southwest Louisiana on which were plotted all the gravity tests (and fields) of less than 25°API . The maps (John, 1992) also show the geologic age trends of production for the Upper, Middle and Lower Miocene and the Upper and Middle Frio. Based on the regional maps, a series of parish maps were created that identified which fields with medium to heavy oil occurrences were located in the geopressured - geothermal corridors. Most fields of interest in south Louisiana have oil gravity between $20 - 25^{\circ}\text{API}$. An example each of the regional and parish maps are shown in Figures 13 and 14 respectively. Based on these maps, fields in the Cameron, Calcasieu, Acadia, St. Martin, and Iberville parishes are located in the Frio (Oligocene) geopressured - geothermal trend. The other fields of interest for GP/GT-TEOR are located in Iberia,

Figure 13. - - Map of southwest Louisiana showing locations of recorded occurrences (indicated by black dots on the map) of 20° - 25° API gravity oil at shallow depth (< 3,001 ft.) and the geologic age trends (from, John, 1992).

Figure 14. - - Map of Calcasieu Parish, Louisiana, showing fields with $< 25^{\circ}$ API gravity oil at shallow depths ($< 3,001$ ft.) and located in the Frio geopressed - geothermal trend (from, John, 1992).

Terrebonne, Lafourche, St. Mary and Plaquemines parishes and these fall in the Miocene geopressured - geothermal fairway. However, before GP/GT-TEOR is undertaken in fields in these areas, they should be studied in greater detail, with attention to prospect geology, engineering, and reservoir production characteristics and with particular reference to source and target reservoirs. As pointed out by Seni and Walter (1991), geopressured - geothermal brine reservoirs do not require structural or stratigraphic closure to trap hydrocarbons as do oil and gas reservoirs. Other factors that would need to be evaluated include brine production technology, methods for surface handling and gas separation from brine, injection technology, and the production and marketing of the oil obtained from the target reservoir.

Unresolved technical issues that need to be addressed in the process of using geopressured - geothermal brine for secondary oil recovery include (1) potential chemical reactions between the injected brine and reservoir fluids, (2) fluid temperatures, (3) brine heat loss in relation to distance and depth of target reservoir, (4) optimum injection pressure and volume rate without inducing fracturing in the target oil reservoir, and (5) the geometry and areal extent (size and thickness) of the geopressured - geothermal reservoir and of the target oil reservoir (from, John, 1992).

Results from the co-location studies at the Bureau of Economic Geology, University of Texas at Austin indicates that in a five county area of South Texas, geopressured - geothermal reservoirs in the Paleocene - Eocene Wilcox Group lie below medium to heavy oil reservoir in the Eocene Jackson Group. This association suggests the use of geopressured - geothermal fluids the deeply buried Tertiary geopressured - geothermal reservoirs could be injected into shallow oil reservoirs to supply both the heat energy and fluid for enhanced oil recovery by steam or hot water flooding. A schematic flow chart illustrating this process is shown in Figure 15. A TEOR

Figure 15. - - Schematic flow chart illustrating a geothermally enhanced oil recovery method utilizing geothermal water from reservoirs in the Wilcox to inject shallow heavy oil reservoirs in the Jackson Group (from, Seni and Walter, 1993).

process would result in energy savings and resource conservation by maximizing the percentage of oil recovered from the reservoir and by eliminating the standard practice of heating the injection fluids through combustion of hydrocarbons. In situations, where steam injection is impractical or uneconomical, injection of geothermally heated water may offer an economically attractive alternative. Although Negus de-Wys and others (1991) suggested that TEOR using geopressured - geothermal fluids could be economically viable in South Texas because of the co-location of geothermal resources below heavy-oil reservoirs, and because of the size of the heavy oil and geopressured - geothermal resources, the geothermal well productivity and dissolved gas content may have been overestimated (from, Seni and Walter, 1993).

Geothermal fairways are generally formed where thick deltaic sandstones are compartmentalized by growth faults. Wilcox geopressured - geothermal reservoirs in South Texas are present at depths of 11,000 to 15,000 ft. in laterally continuous sandstones 100 - 200 ft. thick. Permeability is generally low (typically 1 md), porosity ranges from 12 to 24 percent and temperature exceeds 250°F. Reservoirs containing medium (20 - 25° API gravity) to heavy (10 - 20° API gravity) oil are concentrated along the Texas coastal plain in the Jackson - Yegua barrier strandplain (Mirando trend), Cap rock, and Piercement salt dome plays and in the east Texas basin in Woodbrine fluvial, deltaic, strandplain sandstone and Paluxy fault line plays (Figure 16).

The Jackson - Yegua barrier/strandplain (Mirando trend) is the most favorable play for GP/GT - TEOR of medium to heavy oil because of the abundance of candidate reservoirs, relative simplicity of reservoir architecture, and shallow depth of burial. Updip pinch-out of these shallow sandstones largely controls the distribution of medium to heavy oil reservoirs in the Jackson Group. Subtle structure, small faults, and sandstone - body pinch-outs form lateral barriers of the

Figure 16. - - Map of oil plays in Texas containing medium to heavy oil reservoirs. Numbers indicate names of fields listed on the left side of this figure (from, Seni and Walter, 1993).

reservoirs while structure depositional and diagenetic variations cause reservoir compartmentalization. The medium to heavy oil reservoirs of the Mirando trend are typically porous (25 to 25 percent) and permeable (100 - 1,000 md), slightly clayey, fine to medium - grained sand and sandstones. Calcite cemented zones of low porosity (approximately 5 percent) and permeability (approximately 0.01 md) compartmentalize the reservoirs (from Seni and Walter, 1993).

The Mirando trend occurs in Duval, Jim Hogg, McMullen, Starr, Webb, and Zapata Counties, Texas and lies in the Rio Grande Embayment of South Texas. It is approximately 30 miles wide and 100 miles long (Figure 17). The Texas Railroad Commission records indicate there are 87 fields in the trend, producing oil of 21.5° API gravity or lower. These 87 fields had produced a total of about 320 MMbbls through 1/1/88, and in 1987 showed a production of 1.6 MMbbls. Of the 87 fields, all but 10 recorded production in 1987. The depths of producing reservoirs are 340 to 3,100 ft. If 30% initial recovery is assumed to be represented by 320 MMbbls of recovered oil, then over 1.0 Bbbls of oil remain in place that could be the target of TEOR. Almost half of this is heavy oil. The oil recoveries from most, if not all, of these fields, could be enhanced by a GP/GT fluid injection TEOR program (from Negus de-Wys, et al, 1991, in Malcolm and Light, 1987).

The medium to heavy oil reservoirs account for 8.4 percent of the total oil production from the large reservoirs in Texas (Table 17). The API gravity of the large reservoirs is strongly dependent on reservoir depth (Figure 18). All heavy oil reservoirs are shallower than 6,000 ft. and have an average depth of less than 3,200 ft. The average depth of medium - oil reservoirs is 3,500 ft. The dominant trend is for the oils to become heavier (lower API gravity) and more

Figure 17. - - Location map of heavy oils of South Texas showing the Mirando trend and the location of the Alworth Field (from, Negus de-Wys et.al., 1991, in Hamlin et.al., 1990).

TABLE 17

Comparative statistics of large heavy-, medium-, and light-oil reservoirs in Texas.*

Category	Reservoirs (number)	Total production (MMbbl)	Production (percentage)	Average reservoir production (MMbbl)	Average depth (ft)
Heavy oil	8	999	2.5	125	3,178
Medium oil	38	2,296	5.8	60	3,506
Light oil	415	36,046	91.6	87	6,173
Total	461	39,340	100.0	85	5,940

*List generated from data in Tyler and others (1991).

(from, Seni and Walter, 1993).

Figure 18. - - Graph of API gravity versus depth for all large oil reservoirs in Texas (from, Seni and Walter, 1993).

viscons with decreasing depth. The gravity of oil varies among a group of related reservoirs and even between wells within a single reservoir. Despite this variability, reasonable trends are illustrated (Figure 19) for average API gravity and depth of all reservoirs within plays of the large Texas oil reservoirs. As in individual reservoirs, the average API gravity in shallow plays is lower than the average API gravity in the deeper plays. Five plays containing medium and heavy oil reservoirs are significant for GP/GT - TEOR. These are (1) Jackson - Yegua barrier/strandplain sandstone, (2) Cap rock, (3) Piercement salt domes, (4) Paluxy Fault Line and (5) Woodbine Fluvial/deltaic/strandplain sandstone. Of these plays, the Jackson - Yegua barrier/standplain (Mirando trend) sandstone play has the highest percentage of heavy and medium gravity reservoirs of the large plays. The Woodbine fluvial/deltaic/strandplain sandstone play contains a single supergiant medium to heavy oil reservoir, Hawkins Woodbine. However, oil gravity of individual wells within the Woodbine reservoir varies widely. Of the fine plays listed above, four are characterized by a shallow average depth of less than 4,500 ft., low average API gravity of less than 29° and tight grouping greater than one standard deviation below the API depth trend line. The Cap rock and Paluxy Fault line plays both contain a small number of reservoirs, and the individual reservoirs are in an advanced stage of depletion. The Piercement salt dome and Jackson - Yegua barrier/strandplain sandstone plays both contain heavy and medium gravity oil reservoirs. The greater average depth of the Piercement salt dome play results in a slightly higher average API oil gravity of this play, but medium gravity is characteristic of the shallow reservoirs (from, Seni and Walter, 1993).

Of the groups of wells studied by the Bureau of Economic Geology (BEG), University of Texas at Austin, abandoned gas wells were considered most favorable because they are likely to

Figure 19. -- Graph of average API gravity versus depth for all oil plays in Texas (from, Seni and Walter, 1993).

be deep, to have intact casing, and to have an existing infrastructure of pipelines and other production facilities. Abandoned gas producing wells have the deepest average depth of 14,765 ft. Table 18 lists abandoned gas wells in the South Texas five county area that have a depth below 8,000 ft. and are in the inventory of well logs on file at BEG. A 2.5 mile radius was plotted around abandoned gas producing wells in the South Texas co-location area to determine the extent of co-location of the wells and potential medium and heavy oil reservoirs (Figure 20). It was found that the boundaries of 38 heavy and medium oil fields in the Jackson Group contact or lie within a 2.5 mile radius around abandoned gas wells in the upper Wilcox in the South Texas co-location area. About 35 abandoned gas wells exist within a 2.5 mile radius of a heavy oil or large reservoir field. Fifty-two percent of the heavy oil fields in the South Texas area are within 2.5 miles of an abandoned well in the deep upper Wilcox, whereas sixty-five percent of the large (> 10 Mmbbl) reservoirs in the Jackson Group are within the same radius. Thus, on the basis of surface distance alone, many deep abandoned gas wells are favorably located with respect to heavy and medium oil reservoirs. At the average depth of 14,765 ft. for abandoned gas producing wells in South Texas, the average temperature is estimated to be approximately 377°F (192°C). Abandoned gas wells could form cost-effective conduits for accessing geothermal reservoirs because as a group they are relatively deep and contain relatively hot brines. However, it must be noted that swelling smectite clays occur within Jackson Group reservoir sandstones. When exposed to fresh water, smectite clays will swell and could potentially interfere with reservoir performance by reducing permeability. The Upper Wilcox geopressured - geothermal reservoirs in South Texas probably may not produce brine at a rate of 20,000 bbl / day as was observed in the DOE test well in the Frio Formation at Pleasant Bayou in Brazoria County. However,

TABLE 18

Abandoned Deep Gas Wells in South Texas

Well number	BEG number	Well name	Field name	Reservoir
1	DU-50	Harkins No. 1-A Garza-Cuellar	Los Reyes	Weatherby sand
2	DU-65	Eason-Harper No. 1-160 Peters Estate	Peters S	Wilcox
3	DU-66	Eason No. 1 Peters Estate	Peters S	Wilcox
4	DU-81	K. P. Exploration No. 2 Wm. Hubbard	Leedy	Wilcox 8
5	DU-82	Exxon No. 1 Bravo Land Co.	Rejeletta S	10,000 sand
6	DU-83	Harkins and Co. No. 1 La Venada	La Venada	Weatherby
7	DU-85	Shell No. 1 J. F. Welder Heirs	Bold Forbes	Carrizo P
8	DU-96	Marine Contractors et al. No. 1 Hall-Weiderkehr	Govt. Wells	Mirando
9	DU-97	Fair and Woodward No. 1 J. Luptack	East 76	Wilcox
10	DU-99	Harkins and Co. No. 1-100 D.C.R.C.	Govt. Wells	
11	DU-105	Harkins and McDonald No. 2 D.C.R.C.	Piedre Lumbre	Wilcox W
12	DU-110	Exxon No. 2-H D.C.R.C.	Petrox	Wilcox 7100
13	DU-124	Inland Ocean No. 1 Ross	Labbe S	Wilcox Upper
14	DU-126	Royal Oil and Gas No. 1-R F. Lowe Bindewald	Hostetter S	Wilcox 10,200
15	DU-132	Harkins and Co. No. 1 A. S. Serna	Los Reyes	Weatherby sand
16	DU-141	Shell No. 1 J. S. Garcia	Rosita NW	Wilcox S-8
17	DU-153	Tana Oil No. 1 Hahl		
18	DU-158	T. D. Exploration No. 1 De la Fuente	Herbst-Wilcox	Herbst III
19	WE-2	Houston Oil and Minerals No. 1 F. Billings	Lopez W	Floyd-A
20	WE-16	Hughes and Hughes No. A-1 O. Laurel	Tom Sherman	10500
21	WE-49	E. P. Operating Co. No. 2 A. Z. Laurel	El Milagro	Seventh Hinnant
22	WE-52	Forest Oil No. 1 Rosa V. de Benavides	Cole W	Wilcox
23	WE-56	Conoco No. 1 Carlos Benavides	Picoso	Wilcox 10,300
24	WE-58	Conoco No. B-3 Carlos Benavides	Picoso	Wilcox 11,800
25	WE-59	Conoco No. A-2 Alicia Henry-BMT	Perdido	Taylor Lobo
26	WE-60	Conoco No. A-1 Alicia Henry-BMT	Perdido	Taylor Lobo
27	WE-65	Sagex No. 1 C. B. Dickenson	Picoso E	Carrizo 8000
28	WE-67	Aminoil USA No. 2 Moglia	Moglia	11200
29	WE-68	Forest Oil No. 1 G. C. Villareal GU	Oilton N	10600
30	JH-25	Pan American Sales Corp. No. 3 Gutierrez	Travis Ward	First Hinnant
31	JH-34	Cox and Cox No. 1 A. Martinez	Petroleo	Wilcox
32	ZA-17	Blocker No. 252 Hinnant	Toquachie Creek	
33	ZA-41	Pennzoil Production No. 1 A. R. Gutierrez	Jennings S	Wilcox 8550
34	ZA-46	Houston Oil and Minerals No. 1 Asche	Charco	9100
35	ZA-60	Pennzoil Production No. 1 A. Vela	Comitas SW	7000
36	ZA-63	Samedan Oil No. 1 Maties Unit	Cinco de Mayo	10150
37	ZA-82	Pennzoil Production No. 1 C-1 A. Vela	El Grullo	6760
38	ZA-85	Pennzoil Production No. 1 P. Gonzales Vela	El Grullo	7300
39	ZA-88	Texas Oil and Gas Corp. No. 1 Guerra "M"	Roleta	6800, 7483
40	ZA-92	Gulf Energy and Minerals U.S. No. 1-A G. Gonzalez	Falcon Lake N	Wilcox 6400
41	ZA-100	Good Hope Refineries No. 1 Falcon	Onepol	Wilcox Upper
42	ZA-130	Hughes and Hughes No. G-1 L. A. Hinnant	Aviators S	11800
43	ZA-132	Hughes and Hughes No. M-1 Hinnant	Aviators S	Wilcox 11050
44	ZA-140	Shell Oil No. 1 L. Taylor	El Grullo E	Taylor sand
45	ZA-146	Shell Oil No. 1 G. G. Hinojosa	Fandango	
46	ZA-150	Shell Western E and P No. A-2 H. B. Zachry	Fandango	Wilcox Upper T6
47	ZA-151	Shell Oil No. 3 Muzza	Fandango	Wilcox Upper T6
48	ZA-153	Shell Oil No. 2 L. Garza et al.	Fandango	
49	ZA-156	Shell Oil No. 3 M. T. Longoria	Randado Ranch	Queen City
50	ZA-160	Killam and Hurd No. 2 E. Vela	Wildcat	
51	ZA-170	Pennzoil Production No. 1 A. Garcia	Volpe SE	Wilcox 7730
52	ZA-181	Blocker Explor. No. 1-112 L. A. Hinnant	Toquachie Creek	Wilcox
53	ZA-184	Entex Petroleum No. 1 A. M. Vela	Herfinda Vela	Wilcox
54	ZA-185	Gulf Oil No. 1 Saldana Unit	Martinez	First Hinnant Upper
55	ZA-190	Canus Petroleum No. 1 San Miguel et al.	Cuellar	9215
56	ZA-199	Gulf Oil No. 1 Vela de Peña	Cinco de Mayo	8500
57	ST-12	Border No. 2 N. Silva	Falcon Dam	Wilcox

(from, Seni and Walter, 1993).

Figure 20. - - Map showing the location of deep abandoned gas wells, oil fields in the Upper Jackson, and the South Texas geothermal corridor. A 2.5 miles radius around the abandoned gas wells intercepts more than half of all heavy oil reservoirs in the geothermal corridor. Table 18 lists the following data for numbered abandoned gas wells: unique BEG identification number, operator/well name, field and reservoir (from, Seni and Walter, 1993).

production rates of approximately 1,000 to 2,000 bbl /d, which is probably may be adequate to test the technology for geothermally enhanced oil recovery and to determine engineering data on South Texas geopressured - geothermal reservoirs, in addition to being able to study interactions between geothermal fluids and heavy oil reservoirs (from, Seni and Walter, 1993).

A pilot study on the Alworth field (Figure 17 in Jim Hogg County, Texas, in the Mirando Trend is described in Negus de-Wys et al (1991). Information compiled here on this study is directly taken from this source. The Alworth Field occupies a small structural high about 1.5 miles by 0.5 miles extent. The proposed target reservoir is the Shallow Cole sandstone producing 18.6° API gravity crude from five wells and located at a depth of about 1,000 ft. within the gentle north to south closure that forms Alworth field. A structure map on top of the Cole sandstone and an isopach map of oil column in the reservoir are shown in Figure 21. The characteristics of the target reservoir and the thermal properties of the field are shown in Table 19.

The method of Lauwerier (1955) detailed in a paper titled "The transport of heat in an oil layer caused by the injection of hot fluid" published in Applied Science Research (Sec. A, 5, p. 145) was used to estimate the reservoir temperature distribution with time for hot water injection. Though this method is highly idealized its value lies in its ability to quickly screen the possibilities of heating the reservoir to a desired temperature within a specified time frame. This method assumes the following:

1. A linear, one dimensional, incompressible flow in a homogeneous sand (the reservoir may be substantially heterogeneous).
2. Constant physical properties and fluid saturations (saturations will change with time due to the thermal effect on oil distillation, capillary forces, etc.

Figure 21. - - (A) Structure map on top of the Cole Sandstone, Alworth Field. (B) Isopach map of the oil column in the Cole Sandstone, Alworth Field (from, Negue de-Wys et.al., 1991).

TABLE 19

Summary reservoir data sheet, Alworth Field, South Texas.

Area	=	320 acres
Average Pay Thickness	=	7.5 ft.
Average Porosity	=	30%
Water Saturation (initial) (SWi)	=	46%
Oil Saturation (initial) (SOi)	=	54%
Average Permeability	=	1,500 millidarcies
BHT	=	101°F
BHP	=	350 psi
Depth to Top Soil	=	1,030 ft.
Oil Gravity	=	18.5°API
Oil Viscosity	=	46 centistokes @ 101°F or 48.8 centipoise
Original Oil in Place (OOIP)	=	3,000 Thousand Stock Tank Barrels (MSTB)
Cumulative Recovery To Date	=	100 MSTB or 3.3% OOIP
Current Production	=	20 BOPD, 1,000 BHPD
5 Producers,	1 Injector	2- Shut-in

Reservoir thermal properties, Alworth Field, South Texas

Thermal Conductivity of Overburden	=	34 BTU/ft-day °F
Thermal Conductivity of Reservoir Rock	=	34 BTU/ft-day °F
Density of Overburden (Silty Sand)	=	132 lb/ft ³
Heat Capacity of Overburden (Silty Sand)	=	.288 BTU/lb - °F
Density of Reservoir Rock (Sand Stone)	=	142 lb/ft ³
Heat Capacity of Reservoir Rock (Sand Stone)	=	.252 BTU/lb - °F
Heat Capacity of Water	=	1.0 BTU/lb - °F
Heat Capacity of Oil	=	.4 BTU/lb - °F

(from, Negus de-Wys, et.al., 1991).

3. Uniform temperature for any vertical position within the reservoir.
4. Thermal conductivity is zero in the horizontal direction, and constant injection rate and temperature.

A 10 acre line drive pattern was used to estimate reservoir temperature distribution with time. Specific assumptions were: an injection rate of 375 bbl/day/well (pattern); a volumetric sweep efficiency of 70% with linear flow; an average reservoir thickness of 7.5 ft; injection temperatures of 338 and 482°F (170 and 250°C); a 5 acre pattern element with a width of 330 ft. and a distance between the injection well and production well of 660 ft. At the assumed volumetric sweep efficiency, the pattern element pore volume is 61,000 bbls. At a pattern element injection rate of 187.5 bbl/day, the time to inject 1 pore volume is 326 days.

ECONOMIC ANALYSIS

Oil recovery by TEOR is economically feasible if the net value of the oil recovered per unit time exceeds the total cost of recovery per unit time. A realistic economic evaluation of a TEOR project must be of a specific field because of the unique aspects of each reservoir, associated brine well, and regional costs. The Alworth Field of south Texas is used as an example economic analysis because it is regarded as typical of the heavy oil fields found in the "Mirando" trend. The input data for the Alworth Field pilot study are given in Table 20. These input data were obtained from Fanion Production Company, the Otis Division of Haliburton, Schlumberger Inc., and Watson Pipe and Supply of Corpus Christi, Texas.

The economic model assumes that a suitable geopressured - geothermal well and a suitable target reservoir are available and allows the brine temperature to vary, as well as the distance

TABLE 20

Economic input data for evaluation of Alworth Field.

TEOR Using Geopressured-Geothermal Brine Model Inputs: 8/10/90
 ANALYSIS OF TEOR: SOUTH TEXAS ALWORTH FIELD, UPPER WILCOX FM
 COMPUTER MODEL NAME: 6610-2D
 COMPUTER MODEL DESCRIPTION: Recovery of heavy oil with hot brine

RESULTS: (Assume 1,000,000 bbl recovery, 100 scf/bbl)
 \$/bbl oil recovered \$17.20/bbl (based on \$25/bbl oil)

BASE YEAR and CONTRACT DOLLARS: 1990

COSTS/EXPENSES:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$3,986,000.
 (\$3,624,000 +10% contingency)

Borrowed Capital	\$	
Owners Equity	\$3,650,000	
TOTAL DEVELOPMENT COSTS	\$2,095,000	
Site Procurement/Lease	\$	135,000
Well Study	\$	35,000
Well Engineering	\$	25,000
Well Refurbishment	\$1,650,000	
Well Test	\$	110,000
Disposal Well (field)	\$	140,000
TOTAL EQUIPMENT COSTS	\$1,529,000	
Gas Line	\$	-0-
Transmission	\$	240,000
Site Upgrade	\$	85,000
Brine Separator/Piping	\$	125,000
OIL RECOVERY EQUIPMENT COSTS		
Rework Existing Wells	\$	85,000
Drill New Production and Injection Wells	\$	574,000
Field Study & Design	\$	60,000
Piping for Brine to Field	\$	250,000
Brine Capatibility Study	\$	110,000

WORKING FUNDS	\$	
CAPITALIZED INTEREST	\$	

TOTAL ANNUAL OPERATION EXPENSES \$ 775,000.

Labor and Administration	\$	150,000
Maintenance (% of capital costs)		
Calculated Value	\$	185,000
Scale & Corrosion Inhibitor	\$	90,000
Liability & Operators Extra Exp Insur.	\$	110,000
Data Collection, Lab Work, Samples, etc	\$	240,000

(continued on next page)

TOTAL POST-OPERATION COSTS \$ 185,000
 Site Decommissioning \$ 75,000
 Plug & Abandon \$ 110,000
 SALVAGE \$

FINANCIAL/TAX/ECONOMIC INPUTS:
 Discount Rate (IRR) 15.0%
 Debt Ratio 40.0%
 Interest Rate 11.0%
 Debt Life 5 years
 Depreciation Life 7 years
 Royalty (% of revenue) 15%
 Taxes:
 Federal Tax 38%
 State Tax 5%
 Severance Tax 5%
 Ad Valorem Tax 7.5%
 Inflation Rate 5%
 Escalation:
 Development and Capital Cost 0
 Labor and Administration 0
 Maintenance 0
 Scale Inhibitor 0
 Insurance 0

WELL CHARACTERISTICS:
 Brine Temp at Surace 300F
 Barrels per Day 20,000 BPD
 Gas Concentration/Barrel MIN 35 scf/bbl
 MAX 120 scf/bbl
 Gas Quality 90%
 Well Life 10 years

PRODUCTION FACILITY CHARACTERISTICS: Assume 3 years production
 Annual Gas Production MIN 480,000 Kscf (80 scf/bbl)
 MAX 660,000 kSCF (100 scf/bbl)
 Annual BBLS Oil Prod. 333,333 Barrels (MIN)
 Total BBLS Rating of Facility 1,000,000 Barrels (MIN)
 Operating Factor 95%
 Plant Life 10 years

The above would generate a cash flow after taxes and royalty of 333,333 x
 \$17.20 + 480,000 x \$1.12 = \$6,270,928/yr.

(from, Negus de-Wys et.al., 1991).

between the brine source well and the target well. The results of the two production scenarios are given in Table 21. The distance between the brine source reservoir and the target well is assumed to be 2.5 miles with a brine line cost of \$250,000. Other assumptions are that 90% of the geopressured gas is methane with 80 scf / bbl of brine, and that the gas will be extracted prior to piping the brine into the target well. This allows for revenue from the sale of gas of over \$1,000,000. Another scenario is to pump the gas directly into the target well where it would be used as additional gas drive within the target reservoir. Unfortunately, the GP/GT - TEOR method is an unproven one and therefore there is no body of information from which costs can be accurately estimated, except by comparison with other EOR methods, from, Negar de-Wys et.al., 1991. Details of other economic assumptions and the other financial, operational, and economic variables are provided in Negus de-Wys et.al., 1991.

The concept of using geopressured - geothermal hot brines for thermal enhanced oil recovery seems to promise quick realization, potential industry interest and participation which are vital for full development of the idea. However, more pilot field studies needs to be undertaken in order to fully evaluate the viability of using this method of TEOR. Successful testing of this concept would lead to improved recovery efficiencies and the reworking of presently uneconomic and/or abandoned fields (from, John, 1992).

TABLE 21

Production Scenario 1

Assuming:			
20,000 BPD of hot brine production 80 scf gas/per barrel of hot brine 90% of gas is methane 1,000,000 bbls of heavy oil production over a 3 year period			
Assuming: \$2.25/mcf & \$20.00/bbl			
15% Discount:			
Breakeven	Discounted Payback	NPV	
	years	thousands	
\$1.25/mcf	1.8		\$3,600
\$12.15/bbl oil			
26% Discount:			
Breakeven	Discounted Payback	NPV	
	years	thousands	
\$1.30/mcf	1.9		\$2,300
\$14.25/bbl oil			

Production Scenario 2

Assuming:			
20,000 BPD of hot brine production 80 scf/gas/per barrel of hot brine 90 % of gas is methane 1,500,000 bbl of heavy oil production over a 3 year period			
Assuming: \$2.25/mcf & \$20.00 /bbl			
15% Discount:			
Breakeven	Discounted Payback	NPV	
years	thousands		
\$0.80/mcf	1.2		\$6,500
\$9.25/bbl oil			
26% Discount:			
Breakeven	Discounted Payback	NPV	
years	thousands		
\$1.00/mcf	1.3		\$5,900
\$10.25/bbl oil			

(from, Negus de-Wys et.al., 1991).

APPLICATION OF GEOPRESSURED - GEOTHERMAL RESOURCES TO DIRECT USES

A unique feature of the geopressured - geothermal resource is the possibility of locating several different applications at a common site to improve profitability. For example, one geopressured well could produce desalinated drinking water and bottled water, as well as produce heat for an adjacent agriculture / aquaculture complex. Other options would be to sell the brines resulting from the desalination process and/or to produce and sell electricity. Beyond the potential economic advantages are the safe benefits of using a clean, environmentally safe source of energy. Some of the most promising applications for the geopressured - geothermal fluid involve using its heat, pressure, and natural gas to boost productivity in some industries or to create new industries altogether. The high temperatures, pressures, and natural gas associated with the geopressured - geothermal resource makes it directly applicable not only to supercritical fluid processing and thermally enhanced oil recovery, but also to aquaculture, agriculture, desalination and a host of other industries. From greenhouses to soil warming to fish farming, geopressured fluids can maintain optimum growth temperatures and can improve marketability and profits. Other applications of geopressured - geothermal resources include the following:

- To detoxify waste using supercritical fluid processing
- To recover sulfur
- To provide energy for transporting petroleum or natural gas in pipelines
- To remove sulfur from coal
- To provide a source of heat for drying lumber and concrete products
- To process paper and can sugar

- To supply water and heat for spas
- To provide chemicals which can be extracted for resale

Any of these applications can be explored either alone or in combination with any other direct uses to make an operation more profitable (from, Geopressured - Geothermal energy - the untapped resource. DOE brochure). Figure 22 shows a diagram illustrating the different uses of the geopressured - geothermal resource.

A publication titled "The feasibility of applying geopressured - geothermal resources to direct uses," authored by B.C. Lunis, J. Negus de-Wys, M.M. Plum, P.J. Lienau, F.J. Spencer and G.F. Nitschke and published by EG&G Idaho provides details on this subject. This work was performed by EG&G under DOE contract No. DE-AC07-76ID01570. Information compiled here on this topic is taken directly from this publication. This feasibility study provides a brief overview of the various direct uses that were considered to utilize the relatively clean and environmentally safe energy that is available in the geopressured - geothermal resource, to identify the areas of greatest industry interest, and to identify those applications that appear to have the greatest potential for utilization and impact. The authors obtained the information regarding the various direct uses from industry, academic, government, and other organizations through personal contact, publications, and documentation. Based on the information obtained, thermally enhanced oil recovery, supercritical fluid processing for waste remediation, desalination, and agriculture / aquaculture applications appear to have the greatest potential for significant near - term development. The numerous potential uses of the geopressured - geothermal resource and their approximate process temperature requirements are shown in Figure 23.

Figure 22. - - Diagram illustrating the utilization of the geopressured - geothermal resource (from, Negus de-Wys and Darfman, 1990, in, Industrial Consortium for the utilization of The geopressured - geothermal resource, ed. J. Negus de-Wys, Volume 1).

Figure 23. - - Temperature requirements for potential applications of the geopressedured - geothermal resource at a well site (from, Lunis et.al., 1991).

The sale of gas contained in the geopressured - geothermal fluid will be accomplished irrespective of the applications selected to use the energy contained in the geopressured fluid. Commercialization would also include electric power generation, which was effectively proven at the DOE geopressured test site at Pleasant Bayou; Brazaria County, Texas, located about 50 miles south of Houston. Multiple applications of the geopressured - geothermal resource at a common locations increases the odds of profitability. For example, a complex served by a 20,000 barrels per day geopressured - geothermal well that provides for the sale of the contained methane gas, the sale of potable water produced by desalination, bottled water, and the brines resulting from desalination will have a 15% discounted payback period of about 4.3 years (Figure 24). The addition of an agriculture / aquaculture complex producing roses and catfish that is made up of a 4 acre greenhouse structure, service building, three 20 ft. diameter aquaculture tanks in an enclosure, and an 8 x 45 ft. outdoor raceway would reduce the payback period to about 4 years (Figure 25). However, when electricity production is added to the gas / potable water / bottled water / brine complex, the expected discounted payback period increased to more than 10 years when the electricity is sold for 6 cents / kWh. If the complex is selling gas at market price, electricity at 6 cents / kWh, and includes an agriculture / aquaculture facility, the discounted payback is more than 10 years because of the high front end costs for the electric generation equipment and the relatively small return for the agriculture / aquaculture facility. However, utility restrictions and financial requirements have typically limited these developments because of the complexity of operation and management (from, Lunis, et.al., 1991).

The principal direct use applications in the United States is shown in Table 22. This table shows the breadth of the industry that is supported by a broad based infrastructure of designers

Figure 24. - - Schematic illustration of a feasible desalination facility using the geopressured - geothermal resource (from, Lunis et.al., 1991).

Figure 25. - - Schematic illustration of a feasible desalination / agriculture / aquaculture complex using the geopressured - geothermal resource (from, Lunis et.al., 1991).

TABLE 22
Principal direct use applications in the United States

Application	Resource Temperature	
	°C	°F
<u>Industrial</u>		
Enhanced Oil Recovery		
Amoco, WY	93	200
Heap Leaching		
Round Mountain Gold Corp, NV	85	186
Pegasus Gold Corp Florida Cary, NV	114	238
Food Drying		
Gilroy Foods, NV	132	270
Mushroom Growing		
Oregon Trails Mushrooms, OR	113	235
<u>Heat Pumps (Heating)</u>		
Florida, all of state	24	75
Michigan, all of state	8	47
Indiana, all of state	12	54
<u>Pools/Spas</u>		
Payne's Fountain of Youth RV Park, WY	52	125
Hot Springs State Park, WY	57	135
Hunt's Ash Springs, NV	36	97
<u>Aquaculture</u>		
Hot Creek Hatchery, CA	16	61
Fish Breeders of Idaho, ID	32	90
Hyder Valley, AZ	41	105
<u>Greenhouses</u>		
Troy Hygro, UT	110	230
Burgett Floral Greenhouses, NM	118	245
Utah Roses, UT	51	124
High Country Roses, MT	66	151
<u>Space Heating</u>		
Peppermill Casino, NV	53	127
Residences (505 each), Klamath Falls, OR	93	200
Residences (200 each), Reno, NV	49	120
Merle West Medical Center, OR	88	191
<u>District Heating</u>		
Mammoth Lakes, CA	149	300
Litchfield Correctional Center, CA	77	170
Boise City, ID (two systems)	77	170
San Bernadino, CA	59	138

(from, Lunis, 1990 in, Industrial consortium for the utilization of the geopressured - geothermal resource: Volume 1, ed. J. Negus de-Wys).

and developers who are available to apply their expertise toward the application of hydrothermal direct use projects for geopressured - geothermal resources. In addition to power generation, as mentioned earlier in this compilation, there are numerous industrial, agriculture and aquaculture applications that could use the energy contained in the geopressured fluid and gases. A conceptual layout for a variety of integrated applications is presented in Figure 26.

INDUSTRIAL CONSORTIUM FOR THE UTILIZATION OF THE GEOPRESSURED - GEOTHERMAL RESOURCE

On behalf of DOE, INEL provided the technical support for the assessment and evaluation of the technical and production characteristics of the geopressured - geothermal resource. As a result of these activities an industrial consortium was initiated and held its first planning meeting in September, 1989, at Eaton Operating Company, Houston, TX. This planning meeting was attended by 35 participants, fifteen of whom were from industry. On January 10, 1990, the first consortium meeting was held to present industry cost shared proposals for utilization of the resource. Sixty-five participants convened at Rice University, Houston, Texas, two thirds of whom represented industry. Cost shared proposals included (1) thermal enhanced oil recovery, (2) integrated systems (agriculture / aquaculture), (3) conversion of thermal and hydraulic energy, and (4) use of supercritical water for detoxification of pollutants. Areas for resource utilization and cost shared proposals are shown in Figure 23.

The second meeting of the industrial consortium was held at the University of Texas, at Austin, at the Balcone Research Center on September 11, 1990. The Purpose of this meeting, as was the reason for the first one, was to provide technology transfer to industry and to provide a

Figure 26. - - Conceptual layout of a geopressured integrated facility (from, Lunis, 1990).

forum for teaming of industrial components in addition to providing an avenue by which selected industry cost-shared proposals could be viewed by state and federal agencies as potential programmatic pilot developments. The papers presented at the two industrial consortium meetings were published in 2 volumes for each year's meetings by EG&G Idaho, Inc. and the Idaho National Engineering Laboratory, Idaho Falls, Idaho and were titled "Industrial Consortium for the utilization of the geopressured - geothermal resource". Both of the year's proceedings were edited by J. Negus de-Wys. Details and economics of the projects are presented in these proceedings and the following summary on integrated applications is taken directly from the paper by Ben C. Lunis titled "Geopressured - geothermal direct use developments, published in volume 1 (1990) of the Proceedings . (NOTE: - The complete other author references in the following are also provided at the end of this paper (Lunis, 1990).

POWER GENERATION

Power can be generated utilizing the thermal and hydraulic energy and the gases contained in geopressured resources. Approximately 1 MW of power is presently being generated at the DOE Pleasant Bayou facility located about 50 miles south of Houston, TX. A binary power plant and two gas fired generators are producing the power.

INDUSTRIAL

There are various industrial applications that could utilize the thermal and hydraulic energy found in geopressured resources Following is a brief summary of potential uses and some of the present activities.

Desalination

Fresh water can potentially be removed from geopressured fluids. G.S. Nitschke and J.A. Harris, Wichita State University, are proposing a system that will use the pressure gradient of the reservoir to produce electricity by way of a pressure reduction turbine and generator combination. The natural gas would be separated for sale or on-site use, and the thermal energy would be used to produce potable water through a multi-effect distillation unit. In turn, the remaining saturated brines can be sold. The brine is ideal for solar ponds that utilize binary power generators, a method effectively proven in Israel. The produced potable water can also be used for cooling water for power plants, especially in those areas where potable water supplies are limited. (Nitschke and Harris, 1990)

Gas Use and Sales

Gas contained in the geopressured fluid can be separated, used directly, and/or sold to a pipeline company. This is being done at the DOE Pleasant Bayou facility where each barrel of geothermal fluid contains about 24 scf of methane gas. The gas is sold to a pipeline company and is used in two 325 kW gas engine generators. The gas can also be used for refrigeration and to drive pumps.

Pollutant Removal

The Air Force Engineering and Services Center, the DOE Hazardous Waste Remedial Actions Program, and the Los Alamos National Laboratory are investigating the use of supercritical water (above 705 F and 3208 psia) processes for the destruction of hazardous wastes

(Rofer, 1990). Processing methods appear suitable but require additional development. The feasibility of the utilization of the energy contained in geopressured resources for supercritical water processes is under study at the INEL.

Dr. C. J. Newell, Groundwater Services, Inc., is proposing to use geopressured fluids for the remediation of hazardous waste sites wherein hot water is introduced through patterned drill holes to release the underground waste and pumping it to the surface for additional processing. (Newell, 1990).

Thermal Enhanced Oil Recovery

Geopressured resources, often encountered while drilling for oil and gas, can provide hot brines under pressure to flood reservoirs containing medium or heavy oils to enhance recovery. The INEL is proposing a program for the thermal enhanced recovery of heavy oil from the Alworth Field in the "Mirando" trend of south Texas. It is not possible to consider a hot water-steam type flood in this part of Texas because of the lack of steam quality fresh water. However, geopressured brines can be considered. In the San Joaquin Basin of California, cyclic steam injection has been used successfully but is now under scrutiny because of the pollution generated by the equipment used in producing the steam. In contrast, using geopressured brines offers an environmentally clean process. (Negus-de Wys, 1989).

Sulfur Frasching

Sulfur can be recovered from salt dome deposits using a process devised by Dr. Herman Frasch. This process was perfected commercially in 1903. The technique melts the sulfur while

still underground in porous limestone and calcite deposits. Superheated water (320° to 330° F) under 125 to 200 psi pressure is injected into the sulfur deposits. As the sulfur melts, it is forced to the surface where it can be transported in liquid form, solidified, or made into flakes or pellets, (Carlson, 1976). Adequate pressure and temperature are available in geopressured fluid to perform sulfur Frasching with geopressured fluid.

Petroleum and Natural Gas Pipelining

Petroleum and natural gas pipelining require large quantities of energy to operate the systems. The pipeline companies operate throughout geopressured areas and could benefit from technology developments using the energy available in geopressured resources, (Carlson 1976).

Coal Desulfurization and Preparation

There are a number of processes that are used to process solid or liquid fuel from high-sulfur, high ash coal. Much of the lignite found along the Texas Gulf Coast region is either high sulfur, high ash, or both. These types of processes require large quantities of process heat, pumping, and conveying; geopressured energy could be applicable to all or part of these energy needs, (Carlson, 1976).

Lumber and Concrete Products Kilning

Typical kilns for lumber drying and concrete products require low-quality steam or heated air. These facilities could easily operate with the heat available in geopressured resources,

(Carlson, 1976).

AGRICULTURE AND AQUACULTURE APPLICATIONS

Various agriculture and aquaculture applications are under consideration that could use the fluids and energy found in geopressured resources. One or more of these applications can be installed in cascaded uses where the hot fluids that have been used for one process are then used in another application.

The production of both aquatic and agriculture products are limited commercially by colder winter weather. This in turn disrupts established markets, often making it necessary to create new markets when the products are once again available. Growth rates can be severely hampered by lowered and fluctuating temperatures. For example, alligators grown in Louisiana achieve a marketable length of about 4 ft in 3 y with ambient temperatures. If the surrounding air and water temperature is maintained near 90° F, crocodiles will grow to 7 ft in the same 3 y period, almost doubling the potential income (Ray, 1990). Thus, utilizing the heat and fluid available in geopressured resources for agriculture and aquaculture applications can significantly improve growth rates, marketability, and profits. A brief - summary follows of some agriculture and aquaculture applications under consideration for use at geopressured resources.

Greenhousing

A large variety of fruits, vegetables, flowers, and ornamentals can be grown in geothermally heated greenhouses; this has effectively been proven using hydrothermal resources. The type of product selected for growth at a geopressured site will depend on the market.

Market research is being conducted by organizations such as Agro-Flex, a broad-based, 13 parish nonprofit rural economic development program for southwestern Louisiana. The University of Southwestern Louisiana is proposing to utilize four greenhouses, each planted with a single crop of high density citrus to compare and evaluate with unheated greenhouses and outdoor plots. Heat from a geopressured resource would be applied through different heat exchange mechanisms.

Production Plot Warming and Frost Protection

The growing season for different agricultural products can be extended through the use of geothermally heated fluids in underground piping, or through above ground sprinklers and distribution systems. Citrus production has been limited because of cold weather, and the University of Southwestern Louisiana, in conjunction with the greenhousing effort described above, proposes to use waste geothermal heat as a means of protecting and extending the production of citrus. A 1 acre plot will remain in a natural setting, a second will be heated by installing a subsurface system of hot water, and a third will utilize a warm water sprinkler system, (Huner, 1990).

Rearing of Fish. Crustaceans. Exotics. Turtles. and Alligators

Aquaculture involves the raising of freshwater or marine organisms in a controlled environment to enhance production rates. The principal species being raised are catfish, bass, tilapia, sturgeon, shrimp, and tropical fish. Aquaculture is one of the fastest growing applications for using low-temperature geothermal energy (Lienau and Lunis, 1989). This growth is

in response to an ever increasing demand, especially in Japan and other Asiatic countries.

Controlled rearing temperatures increase growth rates by 50 to 100 percent and thus increase the number of harvests per year. In addition, the use of geothermal fluids in controlled rearing reduces the incidence of disease.

Alligator culture is an emerging and lucrative industry. As previously noted, maintaining growth temperatures at about 90° F can cause an alligator to grow to about 7 ft in 3 y, whereas those grown under ambient conditions only reach a length of 4 ft in the same time period. Fish Breeders of Idaho is planning to utilize their 90° F hydrothermal resource to evaluate the rearing of a small quantity of alligators (Ray, 1990). The University of Southwestern Louisiana is proposing to determine the cost effectiveness of using waste heat from a geopressured facility to warm alligator cultivation units, to evaluate the use of biofilters to control waste levels in culture water, and to observe the benefits of eliminating cold shocks from periodic water changes. They are also proposing to gather baseline data on snapping turtle growth in culture units, to examine the cost effectiveness of rearing soft shell crustaceans and high value ornamental fishes, and to cultivate fingerling food fishes, (Huner, 1990).

Processing

Temperatures available in geopressured resources are generally adequate for food and grain processing, and packaging. Specific applications are determined by market needs, the types of food and grains available, and transportation economics. Cooling needs can be met by using refrigeration units that use energy from the hot geothermal fluids, or from gas-fired units using gas that is available in the geopressured resource. The refrigeration units can also be driven with

electricity from a binary cycle generator installed at the geopressured facility.

PAPER AND CANE SUGAR INDUSTRIES

Numerous pulp and paper mills exist in Geopressured regions. Data assembled in 1975, which provides a relative-value for current considerations, shows that about 38 pulp and paper mills are located in Texas and Louisiana. Eleven mills in these two states are located in potential geopressured regions and had a gross energy consumption of about 78 trillion Btu / years. Louisiana had about 43 raw sugar mills and six sugar refineries that consumed over 12 trillion Btu / years. The overall conclusion of a study made by DSS Engineers, Inc., Ft. Lauderdale, FL, is that utilization of thermal energy from geopressured fluid in pulp and paper mills and new sugar refineries is technically sound and economically feasible, provided that the natural gas and the pressure contained in the fluid is recovered concurrently. Specific studies on sites and facilities are needed (from, Lunis et.al., 1991)

CHEMICAL PROCESSING

The energy contained in geopressured fluids can meet the needs of numerous chemical processes that occur in geopressured regions. Industrial organic chemical processing could amount to about 30.5 trillion Btu for production in Texas and Louisiana (1980 basis) and for inorganics, an estimated 60 trillion Btu / y could be utilized. This potential area of use needs further study.

Geopressured fluids contain varying amounts of different chemicals. Table 23 shows the contents and their amounts found in an analysis of the Pleasant Bayou, TX geopressured well

TABLE 23

PLEASANT BAYOU BRINE ANALYSIS

<u>DESCRIPTION</u>	<u>CONTENT</u>	<u>(MG/L)^a</u>
Spec Gravity @ 60°F		1.080
Total Dissolved Solids	133,900	
Alkalinity (mg C _a CO ₃ /L)	301	
Ammonia	86	
Arsenic	<0.5	
Barium	767	
Boron	25	
Bromide	75	
Cadmium	<0.1	
Calcium	7,960	
Chloride	72,000	
Chromium	<0.1	
Copper	<0.1	
Fluoride	1.6	
Iodide	23	
Iron	45	
Lead	<1	
Lithium	32	
Manganese	16	
Magnesium	604	
Mercury	<0.005	
Nickel	<0.25	
Potassium	561	
Silica (SiO ₂)	108	
Sodium	36,700	
Strontium	850	
Sulfate	6	
Tin	<0.25	
Zinc	0.56	

^a. All results are in milligrams per liter unless otherwise specified.
 Sampled after choke (Negus-de Wys, 1990).

(from, Lunis et.al., 1991)

brine. Certain of these chemicals may be extracted to add to the overall economics of the geopressured facility. Wherever the geopressured fluid shows brine concentrations of at least 60 to 70 ppm, a proven recovery process (Figure 27) may be utilized to release the bromine in pure form. Bromine is a vital ingredient in photographic films. Nearly half of the bromine supply today is derived from seawater and the rest comes from deep underground brines in California, Utah and Arkansas. In a typical case, a single well flowing at a rate of 20,000 bpd and a bromine content of 65 ppm could yield about 450 lb. (100% extraction) of bromine, with a market value of about \$250/day. The concentrated brines from desalination effluent are also rich sources of various chemicals. Their economic extraction may be best accomplished by accumulation in solar ponds from which harvesting and processing of various salts could be undertaken as at the Great Salt Lake in Utah (from, Lunis et.al., 1991).

ECONOMICS

Current economics do allow a geopressured well to be developed for the exploitation of only natural gas because of the high investment costs and the marginal quantity and quality of gas produced. However, because of the size of the geopressured - geothermal resource and the presence of hot fluids under high pressures, it is possible that a mix of applications that exploit these resources could prove to be economical. Specific market needs in geopressured regions will encourage those applications that will produce the greatest net return and benefits. For example, the lower Rio Grande Valley of Texas and the Central Valley of California have the concurrent need of potable water and presence of geopressured resources. Site specific desalination and agriculture / aquaculture applications could result in the profitable development of a geopressured

Figure 27. - - Extraction of bromine from seawater or selected brines (DOW process, modified) (from, Lunis et.al., 1991).

resource.

It is essential that all available options are evaluated and balanced to derive optimal scenarios in which the guiding principle is to extract the highest return on investment under the specific constraints that are imposed upon the installation. The use of other energy forms, such as common fossil fuels and other wastes, biomass, etc. should also be considered so that environmental considerations, conservation of energy, and careful design all contribute to synergy (from, Lunis et.al., 1991).

Generalized economic costs have been developed for various application combinations and these are given in Appendix 3. Throughout the analyses, conservative values were assigned to all cost and revenue items. Obviously, any one cost assumption cannot address all the factors appropriate to a site specific location. It is critical that these generalized costs are not given "gospel" status and are presented as conservative analyses for an assumed installation. Because of the many market and variables any responsible application of technologies that exploit the available energy in a geopressured resource will have to be matched by the economic skills market analyses and product development (from, Lunis et.al., 1991).

The Present Value (PV) methodology is used to calculate the discounted payback and Net Present Value (NPV) of selling a selected array of products from a geopressured-geothermal resource. Often referred to as a Discounted Cash Flow Analysis (DCFA), PV analysis is an economic method or process of equating all past, present, and future costs and revenues to a common point-of-time value. Analysts generally prefer PV analysis over other economic techniques because cash flows are accounted on a real-time, common economic techniques because cash flows are accounted on a real-time, common dollar basis. This common dollar basis

is obtained by discounting all after-tax cash values to a PV cash value using a discount rate. This discount rate is a percentage by which future value dollars are reduced year to year to a present value. Because the discount process substantially reduces the PV of projects with economic lives >5 a year, selection of a discount rate is a very important consideration. A 15% discount rate is a commonly accepted discount rate in developing mineral resources while a 26% discount rate allows for a higher risk typically associated with gas and oil development. Because the cascaded or multi-use of the geopressed-geothermal brine increases the complexity while also diversifying the product mix, a 15% discount rate was assumed.

Results of this study are presented in a discounted payback and NPV analysis. (The breakeven analysis was not used because of the array of combinations available and assigning market ratios between each product). Discounted payback is defined as the minimum time required for the project to generate enough discounted revenues to equal the initial investment of the project. Investors and lending institutions typically use this method to assess the time to recover their investment. The shorter the payback, the less risky the investment because market conditions are less likely to change in the shorter period of time than in a longer period of time. NPV is another method of analysis that determines the net value added to an investment. As the name implies, the initial investment is subtracted from the present value of operating revenues less costs. Again, investors and lending institutions typically use this method of analysis to assess the overall profitability of a project, selecting the project with the greatest NPV (from, Lunis et.al., 1991).

Six combinations of direct use were subjected to economic evaluation that resulted in 15% discounted payback periods ranging from 4 to over 10 years (These are listed on the last page in

Appendix 2). Many other combinations are possible with their selections being established by the developers that chase to co-operatively engage in geopressured resource utilization (from, Lunis et.al., 1991).

The report by Lunis et.al., 1991, from which the information here has been directly compiled, concludes that employment of different direct use technologies, especially desalinated water production, can contribute significantly to the value added process and the overall economic viability in developing a geopressured - geothermal resource. Although greenhouse / aquaculture applications are marginal projects when they are the only use of a geopressured well, the small margin of profitability can contribute to improving the overall economics of the direct use development. The added complexity from a technical and management aspect may add to the overall risk and unpredictability of the project (from, Lunis et.al., 1991).

ENVIRONMENTAL CONSIDERATIONS FOR GEOPRESSURED - GEOTHERMAL DEVELOPMENT

The environmental concerns related to geothermal development were discussed in a book titled "Geothermal direct use engineering and design guidebook" edited by P.J. Lienau and B.C. Lunis (1989) and published by the Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon. This work was sponsored by the U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho under contract No. DE-FG07-87ID12693. Though the information was related to more specifically geothermal development, the same environmental of the geopressured - geothermal resource. Information compiled here on this subject is taken directly from this source.

The degree to which geopressured - geothermal development affects the environment is proportional to the scale of such developments. For example, the environmental impacts associated with geopressured - geothermal direct use projects are often minimal when compared to those associated with large scale electrical generation projects. Direct use projects are generally designed as closed loop systems where the spent fluids are disposed of by subsurface injection. Where surface discharges take place into nearby drainage and/or waterways it makes for much greater environmental concerns than in the case of subsurface injection.

The development of a geopressured - geothermal energy project will be directly or indirectly impacted by various federal, state, and local laws and regulations in its various phases - siting, development and operation. No single set of regulations exist that would apply to all types of geopressured - geothermal applications. It would therefore be important to discuss the different environmental considerations of the project early with all applicable regulatory agencies, in order to obtain the necessary permits to make certain that the project is not impacted because of some over looked environmental regulation (Lunis, 1989). The probability and relative severity of potential environmental impacts as a result of geopressured - geothermal direct use projects is summarized in Table 24.

The regulations affecting geothermal energy development, also valid for geopressured - geothermal development, are summarized in Table 25. A discussion of the major regulations that apply to direct use projects is provided by Lunis (1989) in the publication mentioned at the beginning of this section.

The main environmental factors of concern during geopressured - geothermal development and the operations of direct use projects are as follows:

TABLE 24

Probability and Severity of Potential
Environmental Impacts of Direct Use
Projects.

Impact	Probability of Occurring ^a	Severity of Consequences ^a
Air quality pollution ^b	L	M
Surface water pollution	M	M
Underground pollution ^c	L	M
Land subsidence	L	L to M
High noise levels	H	L to M
Well blowouts	L	L to M
Conflicts with cultural & archeological features	L to M	M to H
Social economic problems	L	L
Chemical or thermal pollution	L	M to H
Solid waste disposal	M	M to H

a. L = Low; M = Moderate; H = High.

b. Hydrogen sulphide odors may be objectionable,
but generally are not significant enough to
be a problem.

c. Pollution concerns may increase with
increasing geothermal fluid injection
requirements.

(From, Lunis, 1989, in Geothermal Direct use Engineering and Design Guidebook, P.J. Lienare
and B.C. Lunis, editors; Geo-Heat Center, Oregon, DOE Contract No. DE-FG07-87ID12693)

TABLE 25
Regulations Affecting Geothermal Energy Development:

Principal Pollution Laws and Regulations	Air	Surface Water	Geothermal Fluids	Solid Waste	Liquid Waste	Noise	Subsidence/ Seismicity
Federal Water Pollution Control Act (NPDES)	--	X	--	--	X	--	--
Safe Drinking Water Act (Underground Injection Control Regulations (UIC))	--	--	X	--	X	--	--
Clean Air Act	X	--	--	--	--	--	--
Resource Conservation and Recovery Act	--	--	--	X	X	--	--
Toxic Substance Control Act	--	--	--	X	X	--	--
National Environmental Policy Act (NEPA)	X	X	X	X	X	X	X
Noise Control Act	--	--	--	--	--	X	--
Geothermal Resource Operations Order #44	X	X	X	X	X	X	X
Occupational Safety & Health Act	X	--	--	X	X	X	--

(from, Lunis, 1989, in Zimmerman, 1984)

1. Airborne effluents
2. Water pollution
3. Land subsidence
4. Induced seismicity
5. Noise
6. Water availability
7. Solid waste
8. Land use
9. Vegetation and wildlife
10. Economic and cultural factors.

(From, Lunis, 1989)

As discussed in Volume II of this compilation, many of these factors were monitored for varying periods of time during the testing of all the wells under the DOE geopressured - geothermal research program. A summary discussion of the ten environmental factors enumerated above is provided in Lunis (1989). Testing and environmental monitoring did not reveal any adverse environmental impact which could be attributed to geopressured - geothermal well testing and production. However, it should be pointed out that all the testing and environmental monitoring work done during the DOE geopressured - geothermal research program was when only a single well was being tested. Successful development of the geopressured - geothermal resource may require the development of a field consisting of larger number of wells, and the environmental conclusions determined on the basis of single well testing may or may not be completely accurate.

The generally site-specific nature of a geopressured - geothermal project makes it difficult to have broad generalizations about the environment risks associated with such project development. However, the process by which such a geopressured - geothermal project development takes place beginning with surface geological and geophysical exploration, leading to site selection, followed by drilling, field development, and facility construction, allows the developer and the regulatory agency the flexibility that is required to provide adequate environmental protection in a cost-effective manner. Experience with the DOE geopressured - geothermal research program has shown that early environmental planning, baseline data gathering, monitoring of ongoing activities, and the timely use of mitigation measures are essential in making an environmentally successful project (Lunis, 1989).

APPENDIX - 1

ECONOMIC ANALYSIS FOR HYDRAULIC ENERGY RECOVERY FROM A GEOPRESSURED - GEOTHERMAL WELL USING A PELTON WHEEL TURBINE

**(FROM: Thurston, G.C. and M.M. Plum, 1991, The Feasibility of Hydraulic energy
recovery from geopressured - geothermal resources: Idaho National Engineering
Laboratory, EG&G, Idaho, Rept. No. EGG-EP-9841,
DOE Contract No. DE-AC07-76ID01570, 27 p + Appendix)**

ANALYSIS OF WELL: High-Pressured Geopressured-Geothermal Well
 MODEL NAME: GG10-C1
 MODEL ANALYSIS: hydraulic energy, pelton wheel, includes 1st of kind costs, breakeven analysis

RESULTS:
 10-YR NPV (\$4,692)
 Discounted Payback > 10 years

BASE YEAR and CONTRACT DOLLARS: 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/COSTS.....	\$510,122
Borrowed	190,344
Owners Equity	309,309
Capitalized Interest	10,469

INVESTMENTS/EXPENSES/REVENUES:

TOTAL PRE-OPERATION/DEVELOPMENT	
CAPITAL COSTS.....	\$510,122
TOTAL DEVELOPMENT COST.....	0
Geopressured-Geothermal	0
TOTAL CAPITAL BUILDING/EQUIPMENT COST.....	454,230
Hydraulic-Turbine	454,230
CONTINGENCIES.....	45,423
CAPITALIZED INTEREST.....	10,469
GROSS OPERATING REVENUES.....	\$140,293
TOTAL COSTS (yr-1).....	63,698
Electricity	57,750
* TOTAL REVENUES (yr-1)	203,991
Electricity	203,991

TOTAL POST-OPERATION COSTS.....	0
---------------------------------	---

SALVAGE (at end of project life).....	0
---------------------------------------	---

* \$.046/kwH, 1990

FINANCIAL/TAX/ECONOMIC INPUTS:

Discount Rate (IRR)	15.0%
Debt Ratio	40.0%
Interest Rate	11.0%
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0%
Taxes:	
Federal Tax	38.0%
State Tax	2.0%
Severance Tax	5.0%
Ad Valore Tax	7.2%
Local Property Tax	0.3%
Inflation Rate	5.0%
Cost Escalation:	
Development and Capital Cost	3.0%
Op/Post-Op Costs/Expenses	0.0%
Revenue Escalation:	
Electricity	1.5%

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERISTICS

Brine Temperature at Surface	282°F
Barrels per Day	24,514 BPD
Gas Concentration/Barrel	80 scf/B
Gas Quality	90%
Estimated Brine Production	10 yrs
Bottom Hole Pressure	15,000 psi
Top Hole Pressure	2,200 psi

ANALYSIS OF WELL: High-Pressured Geopressured-Geothermal Well
 MODEL NAME: GG10-C1
 MODEL ANALYSIS: Hydraulic energy, pelton wheel, includes 1st of kind costs, breakeven analysis.

YEAR	INVESTMENT OWNER EQUITY	kwh GROSS REVENUES	LESS ROYALTY PAYMENT	NET REVENUES	LESS kwh OPER EXPENSES	LESS INTEREST EXPENSES	LESS DEPRECIAT EXPENSES	ADD SALVAGE	TAXABLE INCOME
1991	(\$510)	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$0	\$0
1992	0	204	(31)	173	(67)	(25)	(83)	0	(1)
1993	0	232	(35)	197	(70)	(17)	(62)	0	48
1994	0	247	(37)	210	(74)	(9)	(62)	0	65
1995	0	263	(39)	224	(77)	0	(62)	0	84
1996	0	280	(42)	238	(81)	0	(62)	0	95
1997	0	299	(45)	254	(85)	0	(62)	0	107
1998	0	319	(48)	271	(90)	0	(62)	0	119
1999	0	340	(51)	289	(94)	0	(0)	0	194
2000	0	362	(54)	308	(99)	0	(0)	0	209
2001	0	386	(58)	328	(104)	0	(0)	\$0	224
	(501)	\$2,931	(\$440)	\$2,491	(\$ 841)	(\$51)	(\$454)	\$0	

TAXABLE INCOME	LESS SERVERANCE TAX	LESS ADVALORE TAX	LESS STATE TAX	LESS FEDERAL TAX	ADD DEPRECIAT EXPENSES	INCOME AFTER TAX	PRESENT VALUE	YR TO YR NFV TOTAL
0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	(510)	\$510
(1)	0	0	0	1	94	93	87	(423)
48	(2)	(3)	(1)	(21)	62	82	66	(357)
65	(3)	(5)	(1)	(28)	62	89	63	(294)
84	(4)	(6)	(2)	(37)	62	97	60	(234)
95	(5)	(7)	(2)	(41)	62	102	54	(180)
107	(5)	(8)	(2)	(46)	62	107	50	(130)
119	(6)	(9)	(3)	(52)	62	112	45	(85)
194	(10)	(14)	(4)	(85)	0	82	29	(56)
209	(10)	(15)	(5)	(91)	0	88	27	(30)
224	(11)	(16)	(5)	(97)	0	94	25	(5)
	(\$57)	(\$82)	(\$26)	(\$498)	\$465	\$946	(\$5)	

ANALYSIS OF WELL: High-Pressured Geopressured-Geothermal Well

MODEL NAME: GG10-C1

MODEL ANALYSIS: hydraulic energy, pelton wheel, excludes 1st of kind costs, breakeven analysis

RESULTS:

10-YR NPV (\$1,235)
Discounted Payback > 10 years

BASE YEAR and CONTRACT DOLLARS: 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/COSTS.....	\$285,195
Borrowed	102,310
Owners Equity	177,258
Capitalized Interest	5,627

INVESTMENTS/EXPENSES/REVENUES:

TOTAL PRE-OPERATION/DEVELOPMENT	
CAPITAL COSTS.....	\$285,195
TOTAL DEVELOPMENT COST.....	0
Geopressured-Geothermal	0

TOTAL CAPITAL BUILDING/EQUIPMENT COST.....	254,153
Hydraulic-Turbine	254,153
CONTINGENCIES.....	25,415
CAPITALIZED INTEREST.....	5,627

GROSS OPERATING REVENUES.....	\$ 80,052
TOTAL COSTS (yr-1).....	52,985
Electricity	48,038
• TOTAL REVENUES (yr-1)	133,038
Electricity	133,038

TOTAL POST-OPERATION COSTS.....	0
---------------------------------	---

SALVAGE (at end of project life).....	0
---------------------------------------	---

• \$.030/kWH, 1990

FINANCIAL/TAX/ECONOMIC INPUTS:

Discount Rate (IRR)	15.0%
Debt Ratio	40.0%
Interest Rate	11.0%
Debt Life	3 yrs
Depreciation Life	7 yrs
Royalty (% of revenue)	15.0%
Taxes:	
Federal Tax	38.0%
State Tax	2.0%
Severance Tax	5.0%
Ad Valore Tax	7.2%
Local Property Tax	0.3%
Inflation Rate	5.0%

Cost Escalation:

Development and Capital Cost	3.0%
Op/Post-Op Costs/Expenses	0.0%

Revenue Escalation:

Electricity	1.5%
-------------	------

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERISTICS

Brine Temperature at Surface	282°F
Barrels per Day	24,514 BPD
Gas Concentration/Barrel	80 scf/B
Gas Quality	90%
Estimated Brine Production	10 yrs
Bottom Hole Pressure	15,000 psi
Top Hole Pressure	2,200 psi

ANALYSIS OF WELL: High-Pressured Geopressured-Geothermal Well
 MODEL NAME: GG10-C1
 MODEL ANALYSIS: Hydraulic energy, pelton wheel, excludes 1st of kind costs, breakeven analysis.

YEAR	INVESTMENT OWNER EQUITY	kwh GROSS REVENUES	LESS ROYALTY PAYMENT	NET REVENUES	LESS kwh OPER EXPENSES	LESS INTEREST EXPENSES	LESS DEPRECIAT EXPENSES	ADD SALVAGE	TAXABLE INCOME
1991	(\$285)	\$ 0	\$ 0	\$ 0	\$0	\$ 0	\$ 0	\$0	\$ 0
1992	0	133	(20)	113	(56)	(13)	(55)	0	(11)
1993	0	151	(23)	128	(58)	(9)	(33)	0	28
1994	0	161	(24)	137	(61)	(5)	(33)	0	37
1995	0	172	(26)	146	(64)	0	(33)	0	48
1996	0	183	(27)	155	(68)	0	(33)	0	55
1997	0	195	(29)	166	(71)	0	(33)	0	61
1998	0	208	(31)	177	(75)	0	(33)	0	69
1999	0	221	(33)	188	(78)	0	(0)	0	110
2000	0	236	(35)	201	(82)	0	(0)	0	118
2001	0	251	(38)	214	(86)	0	(0)	\$0	127
	(501)	\$1,911	(\$287)	\$1,625	(\$700)	(\$27)	(\$254)	\$0	

TAXABLE INCOME	LESS SERVERANCE TAX	LESS ADVALORE TAX	LESS STATE TAX	LESS FEDERAL TAX	ADD DEPRECIAT EXPENSES	INCOME AFTER TAX	PRESENT VALUE	YR TO YR NFV TOTAL
0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	\$ 0	(285)	(\$285)
(11)	1	1	0	5	60	56	52	(423)
28	(1)	(2)	(1)	(12)	33	45	36	(233)
37	(2)	(3)	(1)	(16)	33	49	35	(197)
48	(2)	(3)	(1)	(21)	33	54	33	(162)
55	(3)	(4)	(1)	(24)	33	56	30	(129)
61	(3)	(4)	(1)	(27)	33	59	27	(99)
69	(3)	(5)	(2)	(30)	33	62	25	(72)
110	(5)	(18)	(2)	(48)	0	46	16	(47)
118	(6)	(19)	(3)	(51)	0	50	15	(31)
127	(6)	(19)	(3)	(55)	0	54	14	(15)
	(\$32)	(\$46)	(\$14)	(\$280)	\$260	\$530	(\$1)	(1)

APPENDIX - 2

RESULTS OF ECONOMIC ANALYSIS

**(FROM: Propp, W.A., A.E. Grey, J. Negus de-Wys, M.M. Plum and D.R. Haefner, 1991,
Feasibility Study: Application of the geopressured - geothermal resource to pyrolitic
conversion or decomposition / detoxification processes: Idaho National
Engineering Laboratory, EG&G, Idaho, Rept. No. EGG-EP-9842, DOE Contract
No. DE-AC07-76ID01570, 79 p. + Appendices A-B)**

ANALYSIS OF WELL: Typical Geopressured-Geothermal Well
 MODEL NAME: GG10-B1
 MODEL ANALYSIS: electricity production and SCWO reduction of hazardous waste

26-Sep-90 : date
 02:15:25 PM : time

RESULTS :

10-YR NPV \$12,578
 Discounted Payback 10.0 years

BASE YEAR and CONTRACT DOLLARS : 1990

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$18,334,185
 Borrowed 5,700,238
 Owners Equity 12,320,434
 Capitalized Interest 313,513

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$18,334,185
 TOTAL ENV ASSESS & PUBLIC COMMENT . . . 2,783,156
 TOTAL DEVELOPMENT COST 2,546,486
 Geopressured-Geothermal 2,546,486
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST. 9,687,585
 Geopressured-Geothermal 1,148,653
 Disposal 8,538,931
 CONTINGENCIES 3,003,445
 CAPITALIZED INTEREST 313,513

GROSS OPERATING REVENUES \$11,838,599
 TOTAL COSTS (yr-1) 1,652,481
 Electricity 750,727
 Disposal 901,754
 TOTAL REVENUES (yr-1) 13,491,079
 Electricity 1,173,139
 Disposal 12,317,941

TOTAL POST-OPERATION COSTS \$790,014

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 26.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 7 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 1.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.5 %
 Hazardous Waste Disposal 2.0 %

GEOPRESSURED-GEOTHERMAL WELL CHARACTERISTICS :

Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 35 scf/B
 Gas Quality 90 %
 Well Life 10 yrs

REVENUE CHARACTERISTICS :

Generator Capacity 2000 KW
 KWh selling price \$0.060 /KWh
 disposal volume 10,000 gal/da
 average disposal cost \$2.85 /gal

26-Sep-90 : date
02:15:25 PM : time

MODEL INPUTS :

ANALYSIS OF WELL:
Typical Geopressured-Geothermal Well

MODEL NAME:
GG10-B1

MODEL ANALYSIS:
electricity production and SCWO reduction of hazardous waste

Year Costs & Expenses Are Estimated	1990 \$
Year Site Selection Begins	1991
Draft EIS Begins	1991
Year Construction Begins	1994

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount (Internal Rate)	26.0 %
Debt Ratio	40.0 %
Interest Rate	11.0 %
Debt Life	7.0 yrs
Royalty (percentage of revenue generated)	1.0 %
Taxes :	
Federal Tax	38.0 %
State Tax	2.0 %
Severance Tax	5.0 %
Ad Valorem Tax	7.2 %
General Inflation Rate	5.0 %
Cost Escalation :	
Development and Capital Costs	0.0 %
Operation/Post-Operation Costs/Expenses	0.0 %
Revenue Escalation :	
Electricity	0.5 %
Disposal Fee	2.0 %

RESOURCE CHARACTERISTICS:

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERISTICS :

Estimated Brine Production	10 yrs
Barrels per day	20,000 BPD
SCF gas per barrel	35 scf/B
Quality of Gas - methane available	90 .
Brine Temperature at Surface	300 F
Well Loss Characteristics :	
First year of well loss in year	11
Strait-Line loss	0 %

PRE-OPERATION COST :	1990	1991
ENVIRONMENTAL ASSESSMENT & PUBLIC COMMENT :		
Disposal Site Selection	\$100,000	\$105,000
Initial Public Comment	\$150,000	\$157,500
Site Assessment and Characterization . .	\$600,000	\$630,000
		1991
		through
	1990	1994
Draft EIS and Public Comment	\$1,000,000	\$1,050,000
Final EIS and Public Comment	\$500,000	\$551,250
State Permitting, licenses, and fees . .	\$250,000	\$289,406
TOTAL ENVIRON ASSESS & PUBLIC COMMENT . .	\$2,600,000	\$2,783,156
GEOPRESSURED-GEOTHERMAL, WELL-FIELD DEVELOPMENT :		
Site Procurement/Lease	\$135,000	\$164,093
Well Study	\$35,000	\$42,543
Well Engineering	\$25,000	\$30,388
Production Well Development:		
Drilling ofwell(s) . . .	\$0	\$0
Workoverwell(s) . . .	\$1,650,000	\$2,005,585
Disposal/Injection Well:		
Drilling ofwell(s) . . .	\$140,000	\$170,171
Workoverwell(s) . . .		
Well Testing	\$110,000	\$133,706
TOTAL GEOPRESSURED-GEOTHERMAL		
WELL-FIELD DEVELOPMENT COSTS	\$2,095,000	\$2,546,486
RIGHT-OF-WAY COSTS TO SCWO FACILITY . . .	\$0	\$0
GEOPRESSURED-GEOTHERMAL, CAPITAL BUILDING & EQUIPMENT :		
Site Upgrade, Roads, Bldgs	\$350,000	\$425,427
Brine Line to Disposal/Injection well . .	\$100,000	\$121,551
Brine Line to SCWO	\$350,000	\$425,427
Gas Transmission line off-site	\$0	\$0
Capital Equipment:	\$45,000	\$54,698
Pumps/Throttles/Ctrls	\$45,000	
Press Separator-Dehyd	\$0	
Computer	\$0	
Other	\$0	
WORKING FUNDS (Start-up Costs)	\$100,000	\$121,551
TOTAL GEOPRESSURED-GEOTHERMAL		
CAPITAL BUILDING AND EQUIPMENT COSTS . .	\$945,000	\$1,148,653
SCWO OFACILITY CAPITAL BUILDING & EQUIPMENT :		
Brine Line to Injection Wells	\$150,000	\$182,326
Capital Equipment:	\$6,725,000	\$8,174,280
Waste Storage Facility	\$3,200,000	
Compressors	\$225,000	
Inlet Pumps	\$225,000	
Inlet Heat Exc	\$600,000	
Super Critical Reactor	\$1,600,000	
Outlet Heat Exc	\$400,000	
Outlet Pumps	\$150,000	
High Press Separator	\$650,000	
Gas Turbine/Elect Gen	\$1,800,000	
Low Press Separator	\$275,000	
In-plant Piping	\$800,000	
Other	\$0	
WORKING FUNDS (Start-up Costs)	\$150,000	\$182,326
TOTAL SCWO CAPITAL BUILDING		
AND EQUIPMENT COSTS	\$7,025,000	\$8,538,931
		1991
		through
	1990	1994
TOTAL PRE-OPERATION COSTS:		
TOTAL ENVIRON ASSESS & PUBLIC COMMENT . .	\$2,600,000	\$2,783,156
TOTAL DEVELOPMENT COSTS	\$2,095,000	\$2,546,486
TOTAL CAPITAL BUILDING/EQUIPMENT COSTS . .	\$7,970,000	\$9,687,585
CONTINGENCIES OF : 20.0 %	\$2,533,000	\$3,003,445
CAPITALIZED INTEREST		\$313,513
TOTAL PRE-OPERATION COSTS	\$12,598,000	\$15,551,029

ANNUAL OPERATION COSTS :	1990	1995
GEOPRESSURED-GEOTHERMAL/GAS :		
Labor/Administration/Overheads	\$100,000	\$121,551
Maint. % of Cap 7.5 %	\$197,625	\$240,214
Direct Materials: Inhibitors	\$90,000	\$109,396
Liability & Operators Insurance	\$110,000	\$133,706
Data Collection, Labwork	\$120,000	\$145,861
=====		
TOTAL GEOPRESSURED-GEOTHERMAL OPERATION .	\$617,625	\$750,727

GEOPRESSURED-GEOTHERMAL/GAS EQUIPMENT FACTORS:	
Depreciation Life	7 yrs
Actual Operating Life	10 yrs
(to calculate salvage)	

SCWO CONVERTER :		
Labor/Administration/Overheads	\$50,000	\$60,775
Maint. % Cap Eq 2.5 %	\$171,875	\$208,915
Direct Materials	\$100,000	\$121,551
Indirects, % Dir 50.0 %	\$50,000	\$60,775
Liability & Operators Insurance	\$250,000	\$303,877
Data Collection, Labwork	\$120,000	\$145,861
=====		
TOTAL SCWO CONVERTER OPERATION	\$741,875	\$901,754

SCWO CONVERTER EQUIPMENT FACTORS:	
Depreciation Life	7 yrs
Actual Operating Life	10 yrs
(to calculate salvage)	

ANNUAL OPERATION REVENUES :	1990	1995
GAS TURBINE/ELECTRICITY :		
Operating Factor 90.0 %		
Calc Revenues/day, yr-1	\$2,880	
@ 2,000 KW		
contract/market price \$0.060 per KWh		
=====		
ANNUAL GAS REVENUES (yr-1)	\$946,080	\$1,173,139

SCWO CONVERTER/HAZ WASTE DISPOSAL :		
Operating Factor 90.0 %		
Calc Revenues/day, yr-1	\$28,500	
@ 10,000 gal/day		
contract/market price \$2.85 per gal		
=====		
ANNUAL SCWO/DISPOSAL REVENUES (yr-1) . . .	\$9,362,250	\$12,317,941

TOTAL ANNUAL OPERATION COSTS AND REVENUES:	1990	1995
TOTAL GEOPRESSURED-GEOTHERMAL OPERATION .	\$617,625	\$750,727
TOTAL SCWO CONVERTER OPERATION	\$741,875	\$901,754
CONTINGENCIES OF : 10.0 %	\$135,950	\$165,248
=====		
TOTAL ANNUAL OPERATION COSTS	\$1,495,450	\$1,817,729

	1990	1995
=====		
TOTAL ANNUAL OPERATING REVENUES (yr-1) . .	\$10,308,330	\$13,491,079

POST-OPERATION COSTS :	\$	1990	1994
GEOPRESSURED-GEOTHERMAL WELL FIELD:			
Site Decommissioning		\$75,000	\$122,167
Plug & Abandon		\$110,000	\$179,178
SCWO CONVERSION PLANT:			
Site Decommissioning		\$300,000	\$488,668
Plug & Abandon		\$0	\$0
=====			
TOTAL POST-OPERATION COSTS		\$485,000	\$790,014

ANALYSIS OF WELL: Typical Geopressured-Geothermal Well

MODEL NAME: GG10-B1

MODEL ANALYSIS: electricity production and SCWO reduction of hazardous waste - NPV/Dis Payback analysis

26-Sep-90 : date

03:22:01 PM : time

RESULTS :

10-YR NPV (\$6,122,674)
Discounted Payback >10 y years

BASE YEAR and CONTRACT DOLLARS : 1990

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$18,334,185
Borrowed 5,700,238
Owners Equity 12,320,434
Capitalized Interest 313,513

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$18,334,185
TOTAL ENV ASSESS & PUBLIC COMMENT . . . 2,783,156
TOTAL DEVELOPMENT COST 2,546,486
Geopressured-Geothermal 2,546,486
Pipeline Right-of-Way 0
TOTAL CAPITAL BUILDING/EQUIPMENT COST. 9,687,585
Geopressured-Geothermal 1,148,653
Disposal 8,538,931
CONTINGENCIES 3,003,445
CAPITALIZED INTEREST 313,513
GROSS OPERATING REVENUES \$4,022,828
TOTAL COSTS (yr-1) 1,652,481
Electricity 750,727
Disposal 901,754
TOTAL REVENUES (yr-1) 5,675,309
Electricity 488,808
Disposal 5,186,501

TOTAL POST-OPERATION COSTS \$790,014

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 26.0 %
Debt Ratio 40.0 %
Interest Rate 11.0 %
Debt Life 7 yrs
Depreciation Life 7 yrs
Royalty (% of revenue) 1.0 %
Taxes :
Federal Tax 38.0 %
State Tax 2.0 %
Severance Tax 5.0 %
Ad Valorem Tax 7.2 %
Inflation Rate 5.0 %
Cost Escalation :
Development and Capital Cost 0.0 %
Op/Post-Op Costs & Expenses 0.0 %
Revenue Escalation :
Electricity 0.5 %
Hazardous Waste Disposal 2.0 %

GEOPRESSURED-GEOTHERMAL WELL CHARACTERISTICS :

Brine Temp @ Surface 300 F
Barrels per Day 20,000 BPD
Gas Concentration / Barrel 35 scf/B
Gas Quality 90 %
Well Life 10 yrs

REVENUE CHARACTERISTICS :

Generator Capacity 2000 KW
KWh selling price \$0.025 /KWh
disposal volume 10,000 gal/da
average disposal cost \$1.20 /gal

26-Sep-90 : date
02:36:24 PM : time

ANALYSIS OF WELL: Typical Geopressured-Geothermal Well
MODEL NAME: GG10-82
MODEL ANALYSIS: electricity production and SCWO reduction of hazardous waste - LOW RISK SCENARIO

RESULTS :

10-YR NPV \$181,491
Discounted Payback 9.9 years

BASE YEAR and CONTRACT DOLLARS : 1990

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$15,489,013
Borrowed 4,739,427
Owners Equity 10,488,917
Capitalized Interest 260,668

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$15,489,013
TOTAL ENV ASSESS & PUBLIC COMMENT . . . 2,747,287
TOTAL DEVELOPMENT COST 2,309,738
Geopressured-Geothermal 2,309,738
Pipeline Right-of-Way 0
TOTAL CAPITAL BUILDING/EQUIPMENT COST. 8,786,925
Geopressured-Geothermal 1,041,863
Disposal 7,745,063
CONTINGENCIES 1,384,395
CAPITALIZED INTEREST 260,668

GROSS OPERATING REVENUES \$4,545,934
TOTAL COSTS (yr-1) 1,498,849
Electricity 680,932
Disposal 817,917
TOTAL REVENUES (yr-1) 6,044,782
Electricity 556,019
Disposal 5,488,763

TOTAL POST-OPERATION COSTS \$790,014

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 15.0 %
Debt Ratio 40.0 %
Interest Rate 11.0 %
Debt Life 7 yrs
Depreciation Life 7 yrs
Royalty (% of revenue) 1.0 %
Taxes :
Federal Tax 38.0 %
State Tax 2.0 %
Severance Tax 5.0 %
Ad Valorem Tax 7.2 %
Inflation Rate 5.0 %
Cost Escalation :
Development and Capital Cost 0.0 %
Op/Post-Op Costs & Expenses 0.0 %
Revenue Escalation :
Electricity 0.5 %
Hazardous Waste Disposal 2.0 %

GEOPRESSURED-GEOTHERMAL WELL CHARACTERISTICS :

Brine Temp @ Surface 300 F
Barrels per Day 20,000 BPD
Gas Concentration / Barrel 35 scf/B
Gas Quality 90 %
Well Life 10 yrs

REVENUE CHARACTERISTICS :

Generator Capacity 2000 KW
Kwh selling price \$0.030 /Kwh
disposal volume 10,000 gal/da
average disposal cost \$1.38 /gal

ANALYSIS OF WELL: Typical Geopressured-Geothermal Well

MODEL NAME: GG10-B3

MODEL ANALYSIS: electricity production and SCWO reduction of hazardous waste - lower risk scenario

26-Sep-90 : date
02:39:58 PM : time

RESULTS :

10-YR NPV \$151,000
Discounted Payback 9.7 years

BASE YEAR and CONTRACT DOLLARS : 1990

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$17,570,261
Borrowed 5,462,728
Owners Equity 11,807,082
Capitalized Interest 300,450

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$17,570,261
TOTAL ENV ASSESS & PUBLIC COMMENT . . . 2,783,156
TOTAL DEVELOPMENT COST 2,546,486
Geopressured-Geothermal 2,546,486
Pipeline Right-of-Way 0
TOTAL CAPITAL BUILDING/EQUIPMENT COST. 9,687,585
Geopressured-Geothermal 1,148,653
Disposal 8,538,931
CONTINGENCIES 2,252,584
CAPITALIZED INTEREST 300,450

GROSS OPERATING REVENUES \$9,246,634

TOTAL COSTS (yr-1) 1,652,481

Electricity 750,727

Disposal 901,754

TOTAL REVENUES (yr-1) 10,899,115

Electricity 904,294

Disposal 9,994,820

TOTAL POST-OPERATION COSTS \$790,014

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 21.0 %
Debt Ratio 40.0 %
Interest Rate 11.0 %
Debt Life 7 yrs
Depreciation Life 7 yrs
Royalty (% of revenue) 1.0 %
Taxes :
Federal Tax 38.0 %
State Tax 2.0 %
Severance Tax 5.0 %
Ad Valorem Tax 7.2 %
Inflation Rate 5.0 %
Cost Escalation :
Development and Capital Cost 0.0 %
Op/Post-Op Costs & Expenses 0.0 %
Revenue Escalation :
Electricity 0.5 %
Hazardous Waste Disposal 2.0 %

GEOPRESSURED-GEOTHERMAL WELL CHARACTERISTICS :

Brine Temp @ Surface 300 F
Barrels per Day 20,000 BPD
Gas Concentration / Barrel 35 scf/B
Gas Quality 90 %
Well Life 10 yrs

REVENUE CHARACTERISTICS :

Generator Capacity 2000 KW
KWh selling price \$0.045 /KWh
disposal volume 10,000 gal/da
average disposal cost \$2.25 /gal

APPENDIX - 3

INTEGRATED APPLICATIONS ECONOMIC ANALYSES

**(FROM: Lunis, B.C., J. Negus de-Wys, M.M. Plum, P.J. Lienau, F.J. Spencer,
G.F. Nitschke, 1991, The Feasibility of applying geopressured - geothermal resources
to direct uses: Idaho National Engineering Laboratory, EG&G, Idaho,
Rept. No. EGG-EP-9839, DOE Contract No. DE-AC07-76ID01570, 58 p. Appendices A-F)**

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
 MODEL NAME: GG10-A3
 MODEL ANALYSIS: Methane/Salts/Bulk & Bottled Water/Agri & Aqua Products

25-Sep-90 : date
 08:35:39 AM : time

RESULTS :

10-YR NPV \$5,957,976
 Discounted Payback 4.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$6,996,516
 Borrowed 2,469,390
 Owners Equity 4,391,310
 Capitalized Interest 135,816

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$6,996,516
 TOTAL DEVELOPMENT COST 2,199,750
 Geopress-Geothermal Well 2,199,750
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST. . . . 4,037,250
 Geotherm & Elec Eq 199,500
 Gas Separator & Trans 120,750
 Bulk Water/Salt 1,569,750
 Bottled Water 630,000
 Rose/Greenhouse 887,250
 Fish/Aquaculture 210,000
 Working Funds 420,000
 CONTINGENCIES 623,700
 CAPITALIZED INTEREST 135,816

GROSS OPERATING REVENUES \$4,117,857

TOTAL COSTS (yr-1) 1,565,878
 Geopress-Geotherm/Elec 366,450
 Methane Gas 108,806
 Bulk Water/Salt 324,975
 Bottled Water 246,750
 Rose/Greenhouse 338,363
 Fish/Aquaculture 42,000
 Contingencies 138,534
 TOTAL REVENUES (yr-1) 5,683,735
 Geopress-Geotherm/Elec 926,676
 Methane Gas 0
 Bulk Water/Salt 1,626,003
 Bottled Water 1,844,176
 Rose/Greenhouse 1,226,400
 Fish/Aquaculture 60,480

TOTAL POST-OPERATION COSTS \$301,346

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 15.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 3 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 15.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.0 %
 Bulk & Bottled Water/Salts 0.5 %
 Methane Gas 1.0 %
 Fish/Aquaculture 0.0 %
 Roses/Greenhouse 0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life 10 yrs
 Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 80 scf/8
 Gas Quality 90 %
 Bottom Hole Pressure 15,000 psi
 Flowing Wellhead Pressure 2,000 psi

25-Sep-90 : date
08:37:24 AM : time

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
MODEL NAME: GG10-A3
MODEL ANALYSIS: Methane/Salts/Bulk & Bottled Water Products

RESULTS :
10-YR NPV \$4,355,070
Discounted Payback 4.3 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$5,762,988
Borrowed 1,986,500
Owners Equity 3,667,125
Capitalized Interest 109,263

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$5,762,988
TOTAL DEVELOPMENT COST 2,199,750
Geopress-Geothermal Well 2,199,750
Pipeline Right-of-Way 0
TOTAL CAPITAL BUILDING/EQUIPMENT COST. 2,940,000
Geotherm & Elec Eq 199,500
Gas Separator & Trans 120,750
Bulk Water/Salt 1,569,750
Bottled Water 630,000
Rose/Greenhouse 0
Fish/Aquaculture 0
Working Funds 420,000
CONTINGENCIES 513,975
CAPITALIZED INTEREST 109,263

GROSS OPERATING REVENUES \$3,245,176

TOTAL COSTS (yr-1) 1,151,579
Geopress-Geotherm/Elec 366,450
Methane Gas 108,806
Bulk Water/Salt 324,975
Bottled Water 246,750
Rose/Greenhouse 0
Fish/Aquaculture 0
Contingencies 104,698
TOTAL REVENUES (yr-1) 4,396,855
Geopress-Geotherm/Elec 926,676
Methane Gas 0
Bulk Water/Salt 1,626,003
Bottled Water 1,844,176
Rose/Greenhouse 0
Fish/Aquaculture 0

TOTAL POST-OPERATION COSTS \$301,346

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 15.0 %
Debt Ratio 40.0 %
Interest Rate 11.0 %
Debt Life 3 yrs
Depreciation Life 7 yrs
Royalty (% of revenue) 15.0 %
Taxes :
Federal Tax 38.0 %
State Tax 2.0 %
Severance Tax 5.0 %
Ad Valorem Tax 7.2 %
Inflation Rate 5.0 %
Cost Escalation :
Development and Capital Cost 0.0 %
Op/Post-Op Costs & Expenses 0.0 %
Revenue Escalation :
Electricity 0.0 %
Bulk & Bottled Water/Salts 0.5 %
Methane Gas 1.0 %
Fish/Aquaculture 0.0 %
Roses/Greenhouse 0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life 10 yrs
Brine Temp @ Surface 300 F
Barrels per Day 20,000 BPD
Gas Concentration / Barrel 80 scf/8
Gas Quality 90 %
Bottom Hole Pressure 15,000 psi
Flowing Wellhead Pressure 2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
 MODEL NAME: GG10-A4
 MODEL ANALYSIS: Electricity@50.060/Methane/Bulk & Bottled Water Products

25-Sep-90 : date
 08:39:18 AM : time

RESULTS :
 10-YR NPV \$2,862,583
 Discounted Payback 6.2 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$8,867,466
 Borrowed 3,201,660
 Owners Equity 5,489,715
 Capitalized Interest 176,091

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$8,867,466
 TOTAL DEVELOPMENT COST 2,199,750
 Geopress-Geothermal Well 2,199,750
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST 5,701,300
 Geotherm & Elec Eq 2,961,000
 Gas Separator & Trans 120,750
 Bulk Water/Salt 1,569,750
 Bottled Water 630,000
 Rose/Greenhouse 0
 Fish/Aquaculture 0
 Working Funds 420,000
 CONTINGENCIES 790,125
 CAPITALIZED INTEREST 176,091

GROSS OPERATING REVENUES \$3,502,789

TOTAL COSTS (yr-1) 1,465,262
 Geopress-Geotherm/Elec 651,525
 Methane Gas 108,806
 Bulk Water/Salt 324,975
 Bottled Water 246,750
 Rose/Greenhouse 0
 Fish/Aquaculture 0
 Contingencies 133,206
 TOTAL REVENUES (yr-1) 4,968,051
 Geopress-Geotherm/Elec 926,676
 Methane Gas 571,196
 Bulk Water/Salt 1,626,003
 Bottled Water 1,844,176
 Rose/Greenhouse 0
 Fish/Aquaculture 0

TOTAL POST-OPERATION COSTS \$301,346

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 15.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 3 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 15.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.0 %
 Bulk & Bottled Water/Salts 0.5 %
 Methane Gas 1.0 %
 Fish/Aquaculture 0.0 %
 Roses/Greenhouse 0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life 10 yrs
 Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 80 scf/B
 Gas Quality 90 %
 Bottom Hole Pressure 15,000 psi
 Flowing Wellhead Pressure 2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp. Geopressured-Geothermal Well
 MODEL NAME: GG10-A1
 MODEL ANALYSIS: No Electricity/Methane/Salts/Bulk Water Products

25-Sep-90 : date
 08:59:32 AM : time

RESULTS :

10-YR NPV \$546,633
 Discounted Payback 8.2 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$5,054,742
 Borrowed 1,709,400
 Owners Equity 3,251,325
 Capitalized Interest 94,017

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$5,054,742
 TOTAL DEVELOPMENT COST 2,199,750
 Geopress-Geothermal Well 2,199,750
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST. . . . 2,310,900
 Geotherm & Elec Eq 199,500
 Gas Separator & Trans 120,750
 Bulk Water/Salt 1,569,750
 Bottled Water 0
 Rose/Greenhouse 0
 Fish/Aquaculture 0
 Working Funds 420,000
 CONTINGENCIES 450,975
 CAPITALIZED INTEREST 94,017

GROSS OPERATING REVENUES \$1,672,425

TOTAL COSTS (yr-1) 880,254
 Geopress-Geotherm/Elec 366,450
 Methane Gas 108,806
 Bulk Water/Salt 324,975
 Bottled Water 0
 Rose/Greenhouse 0
 Fish/Aquaculture 0
 Contingencies 80,023
 TOTAL REVENUES (yr-1) 2,552,679
 Geopress-Geotherm/Elec 926,676
 Methane Gas 0
 Bulk Water/Salt 1,626,003
 Bottled Water 0
 Rose/Greenhouse 0
 Fish/Aquaculture 0

TOTAL POST-OPERATION COSTS \$301,346

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 15.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 3 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 15.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.0 %
 Bulk & Bottled Water/Salts 0.5 %
 Methane Gas 1.0 %
 Fish/Aquaculture 0.0 %
 Roses/Greenhouse 0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life 10 yrs
 Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 80 scf/B
 Gas Quality 90 %
 Bottom Hole Pressure 15,000 psi
 Flowing Wellhead Pressure 2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
 MODEL NAME: GG10-A2
 MODEL ANALYSIS: No Electricity/Methane/Agri & Aquaculture Products

25-Sep-90 : date
 08:51:16 AM : time

RESULTS :
 10-YR NPV (\$18,902)
 Discounted Payback 0.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:
 TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$4,523,558
 Borrowed 1,501,500
 Owners Equity 2,939,475
 Capitalized Interest 82,583

FINANCIAL/TAX/ECONOMIC INPUTS :
 Discount Rate (IRR) 15.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 3 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 15.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.0 %
 Bulk & Bottled Water/Salts 0.5 %
 Methane Gas 1.0 %
 Fish/Aquaculture 0.0 %
 Roses/Greenhouse 0.0 %

INVESTMENTS/EXPENSES/REVENUES :
 TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$4,523,558
 TOTAL DEVELOPMENT COST 2,199,750
 Geopress-Geothermal Well 2,199,750
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST 1,837,500
 Geotherm & Elec Eq 199,500
 Gas Separator & Trans 120,750
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 887,250
 Fish/Aquaculture 210,000
 Working Funds 420,000
 CONTINGENCIES 403,725
 CAPITALIZED INTEREST 82,583

GROSS OPERATING REVENUES \$1,293,900
 TOTAL COSTS (yr-1) 919,656
 Geopress-Geotherm/Elec 366,450
 Methane Gas 108,806
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 322,613
 Fish/Aquaculture 42,000
 Contingencies 79,787
 TOTAL REVENUES (yr-1) 2,213,556
 Geopress-Geotherm/Elec 926,576
 Methane Gas 0
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 1,226,400
 Fish/Aquaculture 60,480

TOTAL POST-OPERATION COSTS \$301,346
 SALVAGE (at end of project life) \$0

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST
 Well Life 10 yrs
 Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 80 scf/B
 Gas Quality 90 %
 Bottom Hole Pressure 15,000 psi
 Flowing Wellhead Pressure 2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
 MODEL NAME: GG10-A2
 MODEL ANALYSIS: Electricity@\$0.060/Methane/Agri & Aquaculture Products

25-Sep-90 : date
 08:44:33 AM : time

RESULTS :
 10-YR NPV (\$1,511,389)
 Discounted Payback 0.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$7,628,036
 Borrowed 2,716,560
 Owners Equity 4,762,065
 Capitalized Interest 149,411

INVESTMENTS/EXPENSES/REVENUES :

TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$7,628,036
 TOTAL DEVELOPMENT COST 2,199,750
 Geopress-Geothermal Well 2,199,750
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST. 4,599,000
 Geotherm & Elec Eq 2,961,000
 Gas Separator & Trans 120,750
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 887,250
 Fish/Aquaculture 210,000
 Working Funds 420,000
 CONTINGENCIES 679,875
 CAPITALIZED INTEREST 149,411

GROSS OPERATING REVENUES \$1,551,513

TOTAL COSTS (yr-1) 1,233,238
 Geopress-Geotherm/Elec 651,525
 Methane Gas 108,906
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 322,513
 Fish/Aquaculture 42,000
 Contingencies 108,294
 TOTAL REVENUES (yr-1) 2,784,751
 Geopress-Geotherm/Elec 926,676
 Methane Gas 571,196
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 1,226,400
 Fish/Aquaculture 60,480

TOTAL POST-OPERATION COSTS \$301,346

SALVAGE (at end of project life) \$0

FINANCIAL/TAX/ECONOMIC INPUTS :

Discount Rate (IRR) 15.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 3 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 15.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.0 %
 Bulk & Bottled Water/Salts 0.5 %
 Methane Gas 1.0 %
 Fish/Aquaculture 0.0 %
 Roses/Greenhouse 0.0 %

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERIST

Well Life 10 yrs
 Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 80 scf/B
 Gas Quality 90 %
 Bottom Hole Pressure 15,000 psi
 Flowing Wellhead Pressure 2,000 psi

ANALYSIS OF WELL: Large Volume, Moderate Temp, Geopressured-Geothermal Well
 MODEL NAME: GG10-A2
 MODEL ANALYSIS: Electricity@\$0.025/Methane/Agri & Aquaculture Products

25-Sep-90 : date
 08:48:02 AM : time

RESULTS :
 10-YR NPV (\$2,409,299)
 Discounted Payback 0.0 years

BASE YEAR and CONTRACT DOLLARS : 1991

FINANCIAL SUMMARY:
 TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$7,628,036
 Borrowed 2,716,560
 Owners Equity 4,762,065
 Capitalized Interest 149,411

FINANCIAL/TAX/ECONOMIC INPUTS :
 Discount Rate (IRR) 15.0 %
 Debt Ratio 40.0 %
 Interest Rate 11.0 %
 Debt Life 3 yrs
 Depreciation Life 7 yrs
 Royalty (% of revenue) 15.0 %
 Taxes :
 Federal Tax 38.0 %
 State Tax 2.0 %
 Severance Tax 5.0 %
 Ad Valorem Tax 7.2 %
 Inflation Rate 5.0 %
 Cost Escalation :
 Development and Capital Cost 0.0 %
 Op/Post-Op Costs & Expenses 0.0 %
 Revenue Escalation :
 Electricity 0.0 %
 Bulk & Bottled Water/Salts 0.5 %
 Methane Gas 1.0 %
 Fish/Aquaculture 0.0 %
 Roses/Greenhouse 0.0 %

INVESTMENTS/EXPENSES/REVENUES :
 TOTAL PRE-OPERATION/DEVELOPMENT/CAPITAL COSTS \$7,628,036
 TOTAL DEVELOPMENT COST 2,199,750
 Geopress-Geothermal Well 2,199,750
 Pipeline Right-of-Way 0
 TOTAL CAPITAL BUILDING/EQUIPMENT COST. 4,599,000
 Geotherm & Elec Eq 2,961,000
 Gas Separator & Trans 120,750
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 887,250
 Fish/Aquaculture 210,000
 Working Funds 420,000
 CONTINGENCIES 679,875
 CAPITALIZED INTEREST 149,411

GROSS OPERATING REVENUES \$1,218,316
 TOTAL COSTS (yr-1) 1,233,238
 Geopress-Geotherm/Elec 651,525
 Methane Gas 108,806
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 322,613
 Fish/Aquaculture 42,000
 Contingencies 108,294
 TOTAL REVENUES (yr-1) 2,451,554
 Geopress-Geotherm/Elec 926,676
 Methane Gas 237,998
 Bulk Water/Salt 0
 Bottled Water 0
 Rose/Greenhouse 1,226,400
 Fish/Aquaculture 60,480

TOTAL POST-OPERATION COSTS \$301,346
 SALVAGE (at end of project life) \$0

GEOPRESSURED-GEOTHERMAL (brine) WELL CHARACTERISTICS
 Well Life 10 yrs
 Brine Temp @ Surface 300 F
 Barrels per Day 20,000 BPD
 Gas Concentration / Barrel 80 scf/B
 Gas Quality 90 %
 Bottom Hole Pressure 15,000 psi
 Flowing Wellhead Pressure 2,000 psi

Discounted payback periods for various geopressured integrated facilities

<u>Facility Type</u>	<u>15% Discounted Payback Period (y)</u>	<u>10 y NPV^a (\$)</u>
Methane gas/brine salts/bulk and bottled water/agriculture/aquaculture	4.0	5,800
Methane gas/brine salts/bulk and bottled water	4.3	4,355,000
Electricity @ 6 cents/kWh/methane gas/bulk and bottled water	6.2	2,862,600
Methane gas/brine salts/bulk water	8.2	546,600
Methane gas/agriculture/aquaculture	>10.0	(19,000)
Electricity @ 6 cents/kWh/methane gas/agriculture/aquaculture	>10.0	(1,511,400)

^a. Net present value.