Economic Impact of Using Nonmetallic Materials in Low-Intermediate Temperature Geothermal Well Construction

VOLUME I

NOTICE

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FOREWORD

The Process Science Division of the Department of Energy and Environment at Brookhaven National Laboratory has a leading role in the development of safe, reliable, and economical nonmetallic materials for geothermal applications. As part of this effort, the National Water Well Association was awarded a contract to assess the cost-effectiveness and economic impact of using nonmetallic materials in the construction of production and injection wells for various low to imtermediate temperature applications. However, results of this study may be useful in evaluating the economics of using nonmetallic materials in wells designed for mining, subsurface investigations, thermal storage, coal gasification, oil and gas production, brine production, waste disposal, and water supply.

Background information on direct use of geothermal energy, hydrogeology, well design, and materials performance as well as specific economic data provided the basis for cost comparisons and estimates of savings resulting from the use of nonmetallic materials.

EXECUTIVE SUMMARY

This report presents the results of an exhaustive literature search and evaluation concerning the properties and economics of commercially available nonmetallic well casing and screens. These materials were studied in terms of their use in low to intermediate temperature geothermal well construction.

It has been reported that the cost of production and injection wells for geothermal direct-use systems accounts for 50 to 80 percent of the total cost.[17] Direct use of low to intermediate temperature geothermal resources for industrial, commercial, residential, agricultural, and recreational purposes will expand due to the rising cost of conventional fuels and the incentive of geothermal tax credits for homeowners, corporations, and utilities.

Given current estimates of future direct use of geothermal energy between the years 1981 and 2013, potential annual savings of 116 to 442 million dollars could result from the use of nonmetallic materials in geothermal wells. This positive economic impact is based upon the following assumptions:

1. Drilling costs are averaged for each region
2. Casing and screen costs are based on manufacturers' list prices
3. No major maintenance will be required during the service lives of nonmetallic wells
4. The cost of major maintenance for metallic wells is equal to approximately 10 percent of the total current replacement cost
5. Service life is the same for both nonmetallic and metallic wells
6. Inflation rate is 12 percent, compounded yearly
7. Interest rate on borrowed money is 15 percent, compounded yearly
8. Annual savings are based on the number of wells installed between 1981 and 2013 and on all expenditures incurred in maintaining these wells during their service lives

The advantages of nonmetallic well casing compared to metallic well casing include: lighter weight, greater abrasion resistance, smoother walls, greater chemical resistance, higher strength-to-weight ratios, greater resiliency and flexibility, no contamination problems due to the introduction of corrosion products into process streams,

and lower initial cost in some cases. Due to the lighter weight of plastic casing, the energy required to manufacture a length of plastic casing is about one-fourth that required to produce an equivalent length of steel casing.

Disadvantages of nonmetallic casing used in geothermal wells are: low thermal conductivity, low impact strength, decreased stiffness and structural strength at high temperatures, and high coefficients of thermal expansion.

The annual cost of low temperature geothermal wells constructed of nonmetallic materials is less than that of steel wells. This is true for all types of nonmetallic materials suitable for specific geothermal systems in various regions of the United States.

Most of the nonmetallic materials investigated in this report can be divided into two groups on the basis of annual savings when compared with steel wells. These groups and their members are listed in order of decreasing savings: Group I - styrene butadiene rubber, asbestos cement, PVC, and ABS; Group 2 - reinforced plastic mortar, fiberglass reinforced vinylester, laminated wood, fiberglass reinforced epoxy, and CPVC.

Polymer concrete does not fit into either group. It results in the least savings for shallow wells using temperatures less than 82°C (180°F) and for well fields with a large number of deep wells using temperatures less than 121°C (250°F). For most other situations, polymer concrete results in the highest annual savings.

The materials in group 1 are limited to shallow (<305m), (<1000 ft) and relatively low-temperature (<83°C), (<180°F) wells. Of the materials in group 2, fiberglass reinforced epoxy is the best material in terms of stiffness and strength, heat resistance, chemical resistance, ease of installation, and availability.

Based on the results of this study, the following recommendations are proposed:

1. The potential recoverable thermal energy from shallow ground-water reservoirs of ambient temperature should be estimated. Such an estimate should consider limitations of well depth, water temperature, flow rate and quality, and design constraints of ground-water geothermal

heat pumps. The NWWA has already published a detailed map showing shallow ground water temperatures in the contiguous United States.

2. There is a great need for more precise, controlled experiments involving both metallic and nonmetallic materials exposed to various natural and simulated geothermal environments. These experiments will determine the various damage mechanisms and identify those that are the most significant in each case by quantifying corrosion rates of metals and loss of strength of nonmetals.

3. An international survey of the use of nonmetallic casing in low to intermediate temperature geothermal wells should be undertaken. The survey would obtain information on the type of casing used; size, depth, and temperature of well; length of service; and problems and other comments concerning actual field experience.

4. The economics of using nonmetallic casing for geothermal wells should be examined in more detail using site specific data as input for a computer-based model.

5. The economic feasibility of using nonmetallic casing for nongeothermal, energy-related applications (such as uranium leach mining, thermal storage of waste heat, and coal gasification) should be examined.

6. Research should be conducted on the feasibility of fabricating well casing from polypropylene. The low specific gravity, high heat resistance, low water absorption, good chemical resistance, plus low cost of polypropylene make it an ideal material for geothermal well casing.

7. For geothermal wells with water temperatures between 66°-150°C (150°-302°F) and depths less than 2000 m (6562 ft), fiberglass reinforced epoxy casing and screen should be used. For geothermal wells less than 66°C (150°F) and 305 m (1000 ft), PVC should be used or ABS depending upon its availability.

CHAPTER 1. INTRODUCTION

While the world's supply of fossil fuels rapidly diminishes, the cost of these supplies steadily increases. Of more immediate concern is our nation's dependence on foreign oil which places us in an economically weak position when dealing with oil exporting nations and may result in sudden oil shortages and/or price increases. Given this predicament, our nation is compelled to search for additional energy sources.

The development of geothermal resources has become a vital facet of this search. However, due to the severity of geothermal environments, scaling and corrosion problems in well casings and screens present major obstacles to harnessing this form of energy [1]. To avoid this problem, wells can be constructed of low alloy steel casing and screen, which adds significantly to the cost of the well. Fortunately, a number of nonmetallic materials will, under certain conditions, provide the same protective characteristics of low alloy steel, but at a much lower cost. The use of nonmetallic materials could prove to be cost-effective even when corrosion and scaling are not problems.

While geothermal reservoir temperatures can be quite high, this study focuses on the more widespread low-temperature (<90°C), (<194°F) and intermediate-temperature (90° to 150°C), (194° to 302°F) reservoirs. To avoid repetition throughout this report, these two will be referred to as one low-temperature (<150°C) (<302°F) range. Most geothermal sources have temperatures below 150°C (302°F), which is the current threshold temperature for economic electric power generation.[2] Of the identified natural heat sources in the western United States, approximately 85 percent have base temperatures less than 150°C (302°F). In the eastern United States, there appear to be many low-temperature sources. Some space heating systems can use geothermal sources with temperatures as low as 38°C (100°F). With the use of the ground water geothermal heat pump, ground water with temperatures as low as 4°C (39°F) can be used as a heat source for many applications. Thus, the availability and wide applicability of low-temperature geothermal resources compensate for their relatively low energy content.

This report is divided into two volumes. Volume one contains the executive summary, introduction, description of analysis, and discussion of results. Volume two contains appendices which provide detailed information on direct use of geothermal energy, hydrogeologic factors affecting the design and construction of low-temperature geothermal wells, properties of metallic and nonmetallic materials, and special considerations in the design and construction of low-temperature geothermal wells using nonmetallic materials.

Within the last seven years, a considerable amount of research has been done on the performance and economics of various materials in geothermal and nongeothermal environments. The results of some of the more important studies are summarized below.

I. CORROSION AND SCALING IN GEOTHERMAL ENVIRONMENTS

The Radian Corporation compiled a manual of materials-selection guidelines for geothermal power systems [3]. This is the most up-to-date and comprehensive collection of test data concerning metallic and nonmetallic construction materials for power production from liquid-dominated, U.S. geothermal resources. This manual contains data on corrosion rates from materials-performance tests using fluids from five known geothermal resource areas. General guidelines are presented for the use of various materials under different conditions in geothermal power systems.

Brookhaven National Laboratory is investigating alternate construction materials for geothermal applications [4]. The development of a system composed of styrene, acrylonitrile, and acrylamide or methacrylamide and 70-30 sand to portland cement is emphasized since it forms a high-strength, thermally and chemically stable polymer concrete for use in geothermal environments. Results of laboratory and field tests indicated that the materials can be used for casing or protective liners on casing in flowing brine containing 26,000 ppm salt at 240° C (464°F) with little or no corrosion or scaling.

Lawrence Livermore Laboratory investigated the performance of polymeric and composite materials in hot-flowing geothermal brine. The most recent study [5] employed several levels of temperature (60° to 190° C), (140° to 374°F) flow conditions, and duration of exposure. Fluorocarbon and hydrocarbon polymers had the least scale, polyesters and polysulfide had a moderate amount of scale, and reinforced polymers had the most scale. Surface roughness appeared to be an important factor in promoting scaling and scale adhesion.

A study of geothermal corrosion was conducted at the Coso Thermal Area, Naval Weapons Center, China Lake, California [6]. Nine different common construction-grade metallic and nonmetallic piping materials were tested for periods up to one year in three distinctive intermediate-temperature environments (acid-sulfate steam, ground water-diluted steam, and hot, mineralized alkaline water) under aerobic and anaerobic conditions. Corrosion results for the three fluid systems were compared, and specific materials were recommended for use in each fluid type. In general, 304 stainless steel was the most resistant metal while asbestos cement was the most resistant nonmetal. Additional metallic and nonmetallic materials have been tested, but the results will not be available until late 1980.

II. CORROSION IN BRINE WELLS

Oilwell Research, Inc. investigated the cause and prevention of corrosion in the casing, well screen, pump, and pump column of salt-water wells [7]. A major corrosion preventive measure is the selection of optimum materials for corrosion resistance and long life. D-2 Ni Resist, 304 and 316 stainless steels, asbestos cement, and fiberglass reinforced pipe have performed well in casing, well screen, and tubing. Plastic lined and cement lined casings have been used with little success due to coating damage when installing the pump.

III. CORROSION IN DESALINATION PLANTS

The Dow Chemical Company compiled a Desalination Materials Manual [8], which presents test results of metallic and nonmetallic materials in sea water at temperatures up to 121°C (250°F). At high temperatures, Bisphenol-A-Epoxy, halogenated vinylester Derakane, glass reinforced epoxy, and polysulfone gave acceptable results. Factors which ensure maximum life of nonmetallic materials and economic factors in materials selection are discussed.

IV. NONMETALLIC MATERIALS FOR WELL CONSTRUCTION

The American Society for Testing and Materials Task Group on Geothermal Seals held a seminar to stimulate new sealing concepts utilizing available elastomer and other polymer materials, and to produce meaningful ASTM test procedures for geothermal seals [9]. It was concluded that since geothermal conditions are so severe and different from those in other elastomer applications, nearly all previous test data are not applicable. Elastomers for geothermal use must be investigated under the appropriate test conditions of high pressure, reducing atmospheres, and hydrolysis.

The National Water Well Association and the Plastic Pipe Institute collaborated in compiling a manual of installation practices for thermoplastic water well casing [10]. This manual details salient features of drilling and installation techniques using thermoplastic casing. It reviews the state-of-the-art both on a practical (field-oriented) and theoretical basis. It is designed for a wide audience, including water well drillers, hydrogeologists, engineers, and public officials.

Radian Corporation investigated the use of fiberglass reinforced plastic (FRP) pipe for water well applications.[11] Tests were developed and implemented on commercially available FRP pipe. The results of these test can be used in designing an optimum well system. A cost comparison between FRP and metallic casing showed that FRP was more economical than stainless steel and other alloys. Appendices contain information on drilling and casing installation, installation of well screen, and well development.

V. ECONOMICS

A number of acceptable methods are available for an economic comparison of alternate materials for corrosion control. The most common methods -- single payment "Present Worth" or uniform annual series -- "Annual Cost" can be obtained from discounted cash flow analysis. Many researchers [12-14] have used these methods to determine the optimum economical measures for controlling corrosion in various conditions. They emphasized that the economic aspects of solving corrosion problems are more important than metallurgical aspects and corrosion data.

Dow Chemical, U.S.A. compared the installed cost of corrosion-resistant piping [15]. Included in the study are cost ratios and rank-ordering of the installed costs of building both complex and straight-run piping systems based on various materials of construction, labor costs, and construction methods. Various metallic piping, FRP piping, and lined steel piping were compared. The data are presented in a computer-printed format, which is updated periodically. On an installed cost basis, FRP piping is more cost-effective than carbon steel piping.

The University of Colorado and Environmental Consulting Services, Inc. of Boulder, Colorado, collaborated in a study of the technical and economic feasibility of using low-temperature geothermal sources in Colorado [16]. One of the conclusions of this study was that well depth and diameter is a major economic factor only in small- and medium-size district heating systems involving 100 homes or less. Each well should deliver approximately .25 gpm (.016 l/s) of 65°C water to each home, with larger requirements for buildings such as schools and hospitals. Fiberglass reinforced plastic well casing was recommended as an economical substitute for steel casing. Annual maintenance costs for API/K55 steel wells were estimated at six percent of initial equipment costs.

Gruy Federal, Inc. used a computer model, GEODEC, to calculate geothermal well costs for direct use processes [17]. Costs for drilling and casing were estimated from a 1976 study of deep well costs in hard and soft rock formations [18]. Annual maintenance and labor costs were estimated as 10 percent of total capital costs. It was concluded that the wells and equipment for producing and reinjecting geothermal fluids are the major contributors to the cost of geothermal energy. In half of the processes studied, this amounted to 75 percent or more of the total cost.

The present study is unique in that it compares the cost-effectiveness of metallic versus nonmetallic materials, and evaluates the economic impact that the use of nonmetallic well construction materials will have on low to intermediate temperature geothermal energy utilization in the United States.

CHAPTER 2. DESCRIPTION OF ANALYSIS

I. BASIC ASSUMPTIONS

In determining the actual cost of constructing wells so that valid comparisons between alternate materials can be made, the following factors must be considered:

1. Drilling and installation costs in various types of subsurface materials
2. Initial cost of the well casing and screen
3. Transportation costs of the casing and screen
4. Pumping cost
5. Cost and frequency of well maintenance
6. Service lives of various materials in fluids of different temperature and chemistry
7. Replacement costs of the well casing and screen
8. Anticipated inflation rate
9. Interest rate
10. Investment tax credit, where applicable
11. Cost of shutdowns during maintenance and replacement
12. Salvage value, if any

Once this information is collected, it becomes relatively easy to compare the costs of alternate materials by using a capital recovery factor. This will give the annual cost to repay the initial investment plus interest over the lifetime of the well.

If alternative materials have costs which are equal or nearly equal, these costs can be ignored because only differences need be considered.

Some of the cost factors listed previously have been determined from a recent well cost survey, current manufacturers price lists, and conversations with various experts. Other factors were estimated or given average values.

Whether a cost is known or estimated, it is influenced by certain assumptions. These assumptions and their justification will be discussed in the following paragraphs.

A. Drilling Costs

Well drilling costs using steel casing depend on such factors as required yield, hole diameter, type of geologic formation, and well depth. These factors are determined by local conditions and type of geothermal application. Therefore, the cost comparison will include a series of illustrative examples using typical values for specified applications in various ground-water regions of the United States.

Table 2.1 shows the cost per meter for drilling holes of various diameters in the 10 ground-water regions, the predominant types of aquifers in each region, and the typical ranges of maximum yield and well depth in each aquifer. The costs are average values and no attempt was made to distinguish between costs for drilling in different materials in each region. Considering the variety of formations encountered during drilling and the scope of this study, average costs should be used.

The installation cost depends on the ease of handling, joining method, diameter of casing, length of each casing section, and total footage of casing. Generally, installation cost is not specified but is part of the drilling cost. Thus if less time and fewer workers are needed to install a nonmetallic casing, the drilling cost should be lower than the drilling cost for steel casing in similar types of material.

A comparison of drilling costs for PVC and steel [48] showed that drilling costs were approximately 25 percent less for PVC using 152 to 203 mm (6-8 in) casing and 58 percent less for larger diameter casing. This is due primarily to fewer workers and secondarily to the faster rate of installation for PVC (61 m/hr)(200 ft/hr). The same amount of time is required to install other thermoplastics and wood, twice as much time is needed for transite and RPM, and half as much for FRP. The drilling cost for transite and RPM should be reduced 22 percent for 152 to 203 mm (6-8 in) casing and 55 percent for larger casing. For FRP, drilling cost should be reduced 28 percent for 152 to 203 mm (6-8 in) casing and 61 percent for larger casing. The cost of drilling using polymer concrete should be about equal to that of steel since the same amount of labor and time are required.

B. Casing Costs

In Appendix C of Volume II, 20 types of materials are examined in terms of their physical properties and chemical

TABLE 2.1 COST OF DRILLING IN TEN GROUND WATER REGIONS[a] ($/m)

Region	Borehole Diameters (mm)						Aquifers	Maximum Yield (gpm)	Well Depth (m)
	152	203	254	305	356	406			
Western Mountain Ranges	33.50	48.00	59.06	70.87	89.57	114.84	Alluvial	40,000	9-30
							Basalt	110	
							Sandstone	20-1,500	46-610
							and Limestone	Unknown	
Alluvial Basins	36.42	38.55	50.10	60.70		70.41	Alluvial	200-3,000	30-610
Columbia Lava Plateau	32.28	48.52	57.42	85.96		110.73	Basaltic Lavas	5-1,400	27-335
							Alluvial	2,500-35,000	9-46
Colorado Plateau	29.96	36.09	48.39	73.00		91.87	Alluvial	500-1,000	18-91
							Interbedded Shale & Sand-Stone	25-500	27-213
							Limestone	Unknown	
High Plains (b)	14.76	16.73	20.67	24.61	31.99	39.37	Alluvial Interbedded Sandstone, Limestone, Shale	300-30,000	15-213
Unglaciated Central Region	18.44	31.17	44.29	74.91			Alluvial	55-2,000	9-61
							Sandstone	1,000	37-457
							Limestone	Variable	30-183
Glaciated Central Region	27.95	37.73	63.65	90.00			Alluvial	500-1,500	12-335
							Sandstone	500-1,000	61-610
Unglaciated Appalachians	17.91	35.04	49.22	82.03			Metamorphic	20-750	91-152
							Limestone	4-10	61-152
Glaciated Appalachians	23.62	39.80	41.01	61.50			Alluvial	200-3,500	18-61
							Consolidated Sedimentary	100-1,000	15-152
Atlantic and Gulf Coastal Plain	20.47	31.17	46.26	73.13			Semi-Consolidated	150-1,200	3-244
							Consolidated Sedimentary	10-6,500	30-152

(a) Prices based on a recent well cost survey, 48

(b) Cost of drilling using predominantly PVC casing.

resistance. Of these materials, only PVC, ABS, Transite, fiberglass reinforced epoxy, low carbon steel, Type 304 and 316 stainless steel, Monel 400, titanium and polymer concrete have been tested under low-temperature geothermal well conditions. Other materials such as CPVC, styrene butadiene rubber, laminated wood, Techite or RPM, and fiberglass reinforced vinylester have been used successfully as water well casing but have not yet been tested under geothermal conditions.

In the cost comparison, only those materials which are used for well casing and screens will be considered, whether or not they have been tested. The results of a survey of water well contractors who use nonmetallic casing[10] are illustrated in Figure 2.1. Materials not shown were not reported in the survey but their use can be assumed to be less than one percent. Liner materials were not considered as candidate materials for the following reasons: 1) Some liner materials can be easily abraded or shattered during drilling, pump installation, or operation. If a liner is perforated, it no longer protects the steel. 2) Some liner materials have high coefficients of thermal expansion, resulting in separation of the liner from the steel and eventual collapse. 3) The flanged joint, used to couple sections of lined pipe, is not easily adapted to well installations due to its inherent weakness and projecting lip.

Casing and screen costs depend on the diameter, wall thickness, required lengths, and type of joining system used. Diameters considered here range from 152 to 610 mm (6-24 in), depending on yield. Table 2.2 shows recommended casing sizes for various yields. Most nonmetallic casings have diameters of 406 mm (16 in) or less. Steel casing is assumed to be standard weight API 5L Grade A line pipe with plain ends. For more aggressive environments, API Grade K-55 seamless casing is used. Steel screens are either galvanized low-carbon steel or 304 stainless steel.

Figure 2.1

Relative Use of Nonmetallic Materials for Water Wells in the United States

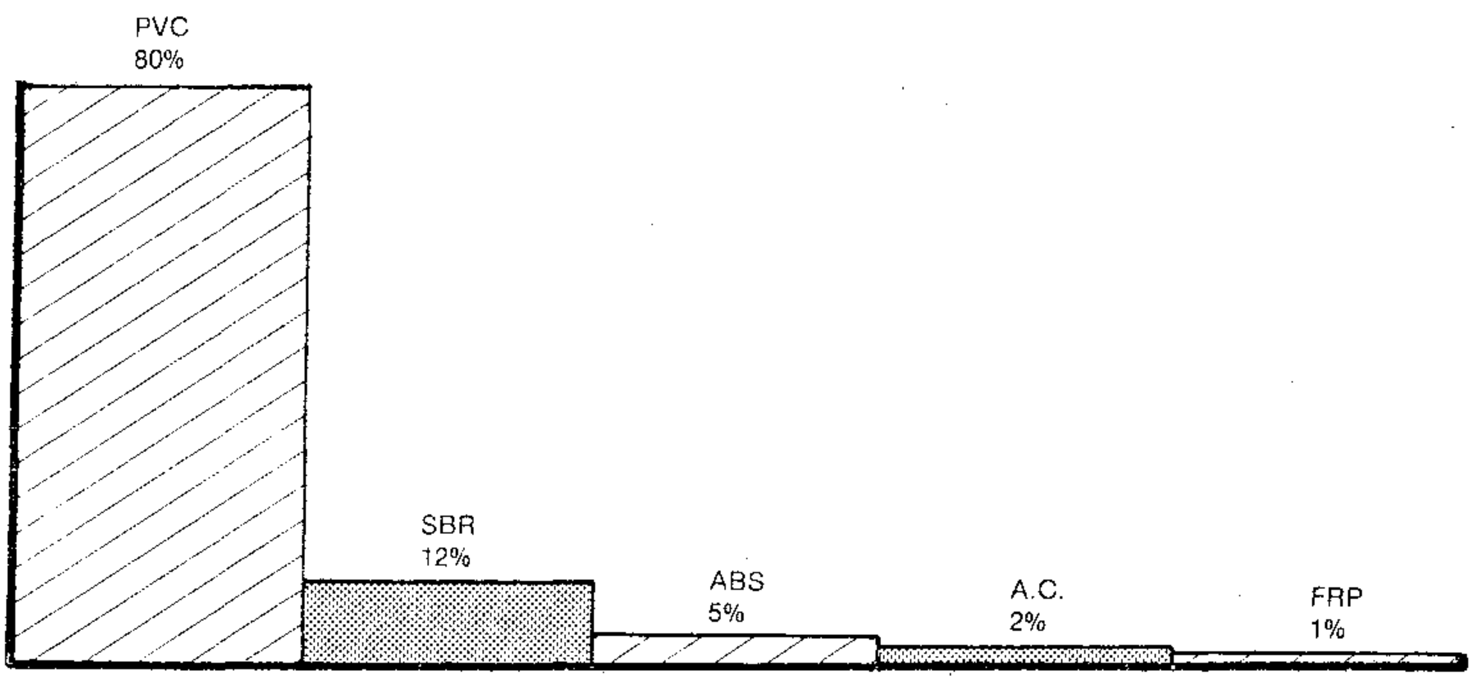


Table 2.2
Recommended Casing Size for Various Well Yields
Using Line Shaft Turbines 1800 RPM

Yield (l/s)	Recommended Casing Size
Less than 6.3	152 mm I.D.
4.7 - 11.0	203 mm I.D.
9.5 - 25.0	254 mm I.D.
22.0 - 38.0	305 mm I.D.
38.0 - 82.0	405 mm O.D.
82.0 - 113.5	508 mm O.D.
113.5 - 189.0	610 mm O.D.
189.0+	914 mm O.D.

The SDR of most thermoplastic well casing varies considerably with well depth and temperature. A small-diameter shallow well may use a casing with an SDR of 26 while the same casing in a deep well may require an SDR of 17. Table 2.3 shows the relationship between SDR classification and Schedule 40 and 80 classifications for various diameter thermoplastic casings.

Table 2.4 lists the cost per meter for various types and grades of casing and screens from 150 to 600 mm (6-24 in) in diameter. Also shown are the casing section lengths and types of joints most commonly used.

Although the prices in Table 2.4 were obtained from various manufacturers and suppliers, the costs should not be considered binding selling prices. Where possible, costs are based on prices of 30 m (100 ft) of pipe for the third quarter of 1979. Actual prices charged by well drillers are slightly below list prices. Therefore, the calculated costs for casing and screen will be conservative values.

C. Transportation Costs

Transportation costs are determined by the distance to the nearest well casing supplier, type of transportation, weight per meter of casing, and whether smaller diameter casings are nested within larger diameter casing.

Distance depends on the region; it is shorter in heavily populated areas and longer in sparsely populated regions. Also, because certain types of casing (such as ABS, RPM, and wood laminate) are manufactured only at one or a few locations, their transportation costs can be quite high.

Table 2.3

Wall Thickness and Tolerances for Thermoplastic Water Well Casing Pipe

(Inches[A])

Nominal Pipe Size	SDR26		SDR21		SDR17		SDR13.5	
	Minimum	Tolerance	Minimum	Tolerance	Minimum	Tolerance	Minimum	Tolerance
2	...	...	0.113	+0.020	0.140	+0.020	0.176	+0.021
2½	...	...	0.137	+0.020	0.169	+0.020	0.213	+0.026
3	...	...	0.167	+0.020	0.206	+0.025	0.259	+0.031
3½	...	...	0.190	+0.023	0.235	+0.028	0.296	+0.036
4	0.173	+0.021	0.214	+0.026	0.265	+0.032	0.333	+0.040
5	0.214	+0.027	0.265	+0.032	0.327	+0.039	0.412	+0.049
6	0.255	+0.031	0.316	+0.038	0.390	+0.047	0.491	+0.058
8	0.332	+0.040	0.410	+0.049	0.508	+0.061	...	...
10	0.413	+0.050	0.511	+0.061	0.632	+0.076	...	...
12	0.490	+0.059	0.606	+0.073	0.750	+0.090	...	...

[A] The minimum is the lowest wall thickness of the well casing pipe at any cross section. All tolerances are on the plus side of the minimum requirement. Multiply by 25.4 to convert to millimeters.

[B] Dimensions below the line meet or exceed Schedule 40 in SDR 13.5, 17, 21 and 26.

[C] Dimensions below the line meet or exceed Schedule 80 in SDR 13.5 and 17.

TABLE 2.4 COST OF METALLIC AND NON-METALLIC CASINGS ($/m)

Material	Grade, Schedule or Depth Range	Diameters (mm) 150		200		250		300		350		400		600		Casing Section Length	Joint
		Casing	Screen	Casing	Screen	Casing	Screen	Casing	Screen	Casing	Screen	Casing	Screen	Casing	Screen	(m)	
Carbon Steel API 5L	A	16.18	108.27	24.34	118.12	34.52	154.21	42.29	196.88	46.56	226.39	53.38	249.36	79.27	380.60	6.1	Welded
API Seamless	K-55	18.54		26.16		42.23		54.04								6.1	Welded
Stainless Steel Type 304	Sch10	45.51	186.03	65.62	230.65	87.27	315.30	110.27	428.50		499.70		559.74		1165.41	6.1	Welded
Thermoplastics ABS(a)	Sch40	20.28	41.34	30.87	73.49	43.28	129.93	46.20	177.17							6.1	Threaded
CPVC(b)	Sch40	37.50	70.31														Cemented
	Sch80	50.69	83.50													6.1	Plain End
PVC(c)	Sch40	15.65	23.72	20.11	37.30	52.10	57.88	69.52	73.26			66.41					Cemented
	Sch80	24.12	32.20													6.1	Plain End
SBR(d)	0-76m	6.89	11.89	7.91	12.91												Cemented
	76-98m	7.58	12.58													6.1	Plain End
Thermosets FRP-(e) Epoxy	0-152m	38.58	46.26	57.98	70.84	85.60	102.10	114.97	134.52	130.52	160.64	165.66	199.03				
	152-305m	48.95	58.53	78.51	96.36	109.03	130.72	152.20	177.93	179.27	217.27	224.03	265.63			6.1	Kwik-key
	305-457m	55.65	67.19	92.89	110.93	127.07	150.86	173.50	206.15	209.59	254.40	265.63	315.73				
FRP-Epoxy(f)	0-2000m	51.51	61.09													6.1	Threaded
FRP-Vinyl-ester(g)	0-366m	34.45	36.25	62.67	68.11	76.28	81.73	86.13	93.34			110.80	118.02			6.1	Threaded
RPM(h)	0-305m			44.29	63.98	52.17	72.84	60.70	82.35	71.20	97.11	79.07	102.70			6.1	Bell & Spigot
Others:																	
Wood(i)	0-610m			62.14	65.88	75.53	79.27	93.71	97.45	112.83	122.74	117.13	127.04	301.23	311.14	1.5	Rivets & Screws
Asbestos Cement(j)		6.00	8.14	8.60	11.65	14.50	18.01	18.70	25.23	24.08		30.35				3-4	Metal Bands
Polymer Concrete(k)		5.87		10.53		18.18		25.82		34.68		41.96		78.02		2.4	Bell & Spigot

(a) DURAPLUS WELLCASE - Manufactured by Slocomb Plastic Pipe & Products, Inc., Slocomb, Alabama.
(b) GEON 3007 - Manufactured by Celanese Piping Systems, Inc., Hilliard, Ohio.
(c) JET STREAM 20376 - Manufactured by Jet Stream Plastics, Siloam Springs, Arkansas.
(d) Manufactured by Jess & Lowell, Denver, Colorado.
(e) KWIK-KEY CASING - Manufactured by Fiberglass Resources Corp., Farmingdale, New York.
(f) Manufactured by Fiberglass Systems, Inc., Big Springs, Texas.
(g) EON Well Casing - Manufactured by Burgess Well Co., Inc., Minden, Nebraska.
(h) TECHITE Well Casing - Manufactured by Amoco Reinforced Plastics Co., Riverside, California.
(i) SBF-obo Well Casing - Distributed by McCausey Lumber Co., Detroit, Michigan.
(j) TRANSITE Class 3300 Sewer Pipe - Manufactured by Johns Manville Corp., Denver, Colorado.
(k) Not manufactured yet (Prices based on materials costs and fabrication cost for concrete pipe).

One advantage of nonmetallic casing is that more casing can be transported per truckload by stacking small-diameter casing inside larger diameter casing. Also, flying the material in by plane or helicopter may prove to be less expensive in some cases.

Transportation costs are an important concern to the casing supplier and well driller but not necessarily to the well owner. Therefore, they will not be included in the cost comparisons.

D. Pumping Costs

Nonmetallic casing materials, especially thermoplastic and fiberglass-reinforced plastic, have lower roughness coefficients than steel. This tends to reduce friction loss and, consequently, pumping costs. In addition, the friction loss in plastic casing remains relatively constant while friction loss in steel casing decreases over time due to incrustation and corrosion.

However, the difference in friction loss between steel and plastic casing may not be great enough to derive any significant savings in pumping costs. For example, the difference in friction head between FRP and old steel is .73 meter when pumping 31.5 l/s (500 gpm) through 305 m (1000 ft) of 305 mm (12 in) pipe. This results in a savings of $94.30 per year in pumping costs. If the steel is new, savings drop to only $12.57 per year. This small difference is not significant and will not be included in the cost comparison.

E. Maintenance Charges

Good well design, based on the awareness of hydrogeological conditions, type of geothermal application, and limitations of casing materials, is the key to successful well performance and, consequently, minimal and effective well maintenance. Based on conversations with numerous water well contractors and casing manufacturers in different parts of the country who have installed various types of nonmetallic casings for up to 16 years, these wells do not seem to require frequent maintenance. There were no reported instances of wells needing maintenance due to corrosion and/or scaling. One manufacturer stated that a downhole camera survey of an FRP vinylester well that had been in service for 16 years revealed no sign of deterioration. The same manufacturer reported good results using FRP vinylester in a 366-m (1200 ft) well that pumped water of 93° C (200°F)[20]. One driller reported no maintenance problems with PVC in an area where steel wells normally survive about five years. Steel wells installed in West Pakistan experienced decreased yields after six months of operation. This decline was due to scaling caused by sulfate-reducing bacteria. FRP casing and screens were then installed in 4,000 wells and these have performed successfully since 1965 with no maintenance problems. These wells have been operating with water containing 200 to 3,000 ppm salt [21].

In another case, 203- and 254-mm (8 and 10 in) FRP casing was used in a 518-m (1700 ft) deep well with little or no maintenance. Some companies have used FRP casing in salt water wells for 10 years with no deterioration or corrosion. On the other hand, steel casing in salt water wells requires constant attention [11]. In addition, a well maintenance and rehabilitation survey by NWWA revealed that water well contractors, hydrogeologists, and well rehabilitation specialists recommended the use of plastic well casing and screen to prolong the life of a water well and to eliminate maintenance and rehabilitation [22]. Thus, maintenance cost and frequency will not be a factor in the case of nonmetallic casings and screens. However, maintenance is very important when using metallic casing.

Table 2.5 lists the frequency of major maintenance for municipal water supply wells based on service records of steel wells of average design that are pumped continuously at or near their maximum capacities [22]. The cost of major maintenance is considered equal to approximately 10 percent of the total current replacement cost. Major maintenance is necessary when the sustained yield or well efficiency declines by as much as 40 percent. It includes well redevelopment techniques such as acid treatment, sonic well cleaning, blasting, and replacing damaged casing and screen.

Table 2.5 also indicates commonly encountered maintenance problems and aquifer types prevalent in the 10 ground-water regions. Maintenance problems are apparently much more closely related to aquifer type than to geographic location. Any variations caused by differences in mean annual temperature are masked by widely varying inorganic and organic chemical and biological factors at specific sites.

F. Service Life

The service life of a well casing depends on the type of casing material, thickness, conditions of use, maintenance,

Table 2.5

MAINTENANCE FREQUENCIES AND SERVICE LIVES OF STEEL WELLS IN TEN GROUND WATER REGIONS

GROUND WATER REGIONS	MOST PREVALENT WELL TYPES	*MOST PREVALENT WELL PROBLEMS	** MAJOR MAINTENANCE FREQUENCY REQUIREMENT (MUNICIPAL)	SERVICE LIVES Domestic	Irrigation	Municipal
1. Western Mountain Ranges	Alluvial	Silt, clay, sand intrusion; iron; scale deposition, biologic fouling.	2 - 5 years	40-50	5-10	30-40
	Sandstone	Fissure plugging, casing failure, sand production.	6 - 8 years	30-35	12-17	30-35
	Limestone	Fissure plugging by clay and silt; mineralization of fissures.	8 -12 years	20-30	5-15	20-30
2. Alluvial Basins	Alluvial	Clay, silt, sand intrusion; scale deposition; iron; biologic fouling; limited recharge, casing failure.	2 - 5 years	40-50	5-10	30-40
3. Columbia Lava Plateau	Basaltic Lavas	Fissure and vesicle plugging by clay and silt; some scale deposition.	6 -12 years	50+	50+	50-100
	Alluvial	Clay, silt, sand intrusion; scale deposition, iron, manganese, biologic fouling.		40-50	5-10	30-40
4. Colorado Plateau Wyoming Basin	Interbedded Sandstone & Shale	Low initial yields, plugging of aquifer during construction by drilling muds, and fines (clay and silt) natural to formations; fissure plugging; limited recharge; casing failure.	4 - 7 years	25-30	8-14	30-35
5. High Plains	Alluvial	Clay, silt, sand intrusion, scale deposition, iron, biologic fouling, limited recharge.	2 - 5 years	40-50	5-10	30-40
	Interbedded Sandstone, Limestone, Shale	Low initial yield; plugging of voids and fissures; poor development and construction; limited recharge.	4 - 7 years	2[illegible]	7-14	25-33
6. Unglaciated Central Region	Alluvial	Clay, silt, sand intrusion; scale deposition; iron; biologic fouling.	2 - 5 years	40-50	5-10	30-40
	Sandstone	Fissure plugging by clay and silt, casing failure, corrosion, salt water intrusion, sand production.	6 - 8 years	30-35	12-17	30-35
	Limestone	Fissure plugging by clay, silt, carbonate scale; salt water intrusion.	5 -10 years	20-25	5-10	20-25
7. Glaciated Central Region	Alluvial	Clay, silt, sand intrusion; scale deposition iron; biologic fouling;	2 - 5 years	35-40	8-14	30-3[illegible]
	Sandstone	fissure plugging; sand intrusion; casing failure.				
8. Unglaciated Appalachians	Metamorphic	Low initial yield; fissure plugging by silt and clay; mineralization of fissures;	12 -15 years	50+	50+	50-100
	Limestone	predominately cavernous production; fissure plugging by clay and silt; mineralization of fissures.	8 -12 years	20-[illegible]	5-15	20-30
	Alluvial	Clay, silt, fine sand intrusion; iron; scale, biologic fouling.	1 - 3 years	20-[illegible]	[illegible]	20-30
9. Glaciated Appalachians	Alluvial	Clay, silt, sand intrusion; scale deposition; biologic fouling; iron	1 - 5 years	35-[illegible]	4-8	25-35
	Consolidated Sedimentary	fissure plugging, mineralization; low to medium initial yield.	6 - [illegible] years	[illegible]	[illegible]-14	25-33
10. Atlantic and Gulf Coastal Plain	Semi-Consolidated Consolidated Sedimentary	Clay, silt, sand intrusion; mineralization of screens of sand and gravel wells; fissure plugging and mineralization of limestone aquifers in the interbedded sand, gravel, marl, clay, silt, limestone formations; biologic fouling of shallower zones; variable iron precipitation.	5 - [illegible] years	40-50	5-12	30-50

* Excluding pumps and declining water table.
** For wells being pumped at near capacity.

ESTIMATES OF MAJOR MAINTENANCE FREQUENCIES ARE BASED UPON THE FOLLOWING ASSUMPTIONS:

1. Wells are yielding at the highest sustained (24 hours per day, every day) yield that they are capable of producing.
2. Major maintenance is required when the sustained yield is 60 percent or less of the initial yield, or the efficiency decreases to the [illegible] percent level.
3. Major maintenance is considered to represent a cost expenditure of approximately 10 percent of the total current replacement cost. Minor maintenance is excluded.
4. Wells are designed in accordance with current practices, not necessarily in accordance with best available technology.

and well design. Typical service lives for carbon steel domestic, irrigation, and municipal wells in various aquifers in the 10 ground-water regions are presented in Table 2.5. The large difference in service life between irrigation wells and domestic and municipal wells is due to the underdesigning of irrigation wells by using less expensive, thin-walled casing. This results in smaller initial cost, but the total cost over the lifetime of the irrigation project may be higher than if a better designed well had been initially installed.

The wells in Table 2.5 are predominantly drilled in shallow ground-water reservoirs of ambient temperature and quality. For geothermal applications, these conditions would be encountered only with wells supplying water to ground-water geothermal heat pumps. Low-temperature geothermal wells that encounter higher temperatures and acidity would have shorter service lives and more frequent maintenance.

Unfortunately, the lack of data has prevented any comprehensive study of the service lives and maintenance frequencies of geothermal wells. However, an economic model for geothermal cost analysis used performance data on metal pipes for corrosive fluid transmission to calculate geothermal well service lives [23]. For geothermal wells in oxygen-free brine of 150°C (302°F) and pH 7 or greater, a service life of 30 years was calculated. This is similar to the minimum service life of most municipal wells in Table 2.5. Geothermal wells in lower temperature reservoirs would have lives approaching the maximum life of municipal wells in Table 2.5.

Most low-temperature geothermal resources have favorable composition; severe corrosion leading to frequent maintenance and short service life is a problem only when oxygen accidentally enters the wells [24]. Thus, values within the ranges for municipal wells should be valid for most geothermal wells. However, wells that house downhole heat exchangers should have a range similar to domestic wells since continuous fluid production is not required for DHE wells. This was observed in one study where the service life of casing was 50 years.[25]

Corrosion is usually a problem in acidic brines. With a pH between 6 and 7 and temperatures less than 93°C (200°F), the service life and maintenance frequency is approximately half; a pH between 4 and 6 with temperature below 93°C (200°F) will give values about one-sixth as great. For acid brines with pH less than 4 and temperatures less than 150°C (302°F), stainless steel should be used to regain the maximum service life [23].

The use of nonmetallic materials in corrosive environments similar to geothermal wells is so recent that determining service lives based on past experience is impossible. FRP epoxy casing has been used for over 25 years to combat severe corrosion in hot brine wells. Wood casing has been used for about 30 years. The majority of nonmetallic casings have been on the market for less than 25 years. This does not mean that the materials will not last much longer. It simply means that the industry is still relatively young and the service period has not yet had time to accumulate.

Based on conversations with water well contractors and manufacturers of nonmetallic casings and screens, estimates of service lives for various materials have been obtained. Some of these estimates are based on laboratory tests. All of them assume ambient ground-water quality and temperature. PVC was given a service life greater than 40 years. Transite was reported to last between 25 and 40 years. RPM service life was estimated at 100 to 125 years. Laminated wood casing has a useful life greater than 30 years. FRP, ABS, polymer concrete, and SBR are reported to last indefinitely. For this study, all nonmetallics will be given a service life equal to steel. This would be a conservative estimate for most nonmetallic casings.

It is assumed that the above materials will not be subject to temperatures, depths, and pressures that will result in casing collapse, and that higher grades will be used as temperature and depth increase. Thus, certain materials will be removed from consideration for use in deep, hot water wells. For a more detailed discussion of the factor involved in determining maximum depth, see Appendix C of Volume II.

G. Replacement Cost

A well will have to be replaced if maintenance cannot restore its initial yield for long periods of time or if the well suddenly fails due to collapse or excessive sand pumping. If the casing is too deteriorated, it may be impossible to pull it out of the hole so that new casing can be installed. In this case, the well will have to be abandoned and a new one drilled nearby. It is assumed that failure of low-temperature geothermal wells will result in their abandonment.

The cost of replacing a well will be more than the original cost due to inflation. This study assumes an inflation rate of 12 percent based on a recent well cost study [26]. Past inflation figures indicate that this assumption is conservative.

H. Interest Rate Factors

All companies recognize that the value of money is of primary importance. They must be able to put a value on what they will pay for money lent to them, or on what their funds can generate in terms of return on investment. It is immaterial whether one thinks in terms of payout period (i.e. how long it takes for an investment to return its incremental cost) or return on investment.

Future and present worth are fundamental to understanding the value of money. Present worth is the amount of money that must be invested today so that enough money is available in the future to replace or maintain the well throughout its service life. Future worth is the present worth compounded for "n" years at a specific interest rate.

For the purposes of this study, an interest rate on borrowed money of 15 percent will be used.

I. Downtime and Salvage

The cost of downtime during well maintenance or replacement is not considered significant for two reasons: maintenance and replacement do not occur very often and lost production or energy savings can usually be made up.

The salvage value of a failed well casing is also not significant because the high cost of recovering the casing is many times greater than the salvage value.

II. BASIC EQUATIONS

Several acceptable methods are available for economic comparisons of alternative corrosion-resistant materials. One common method is the equal-payment-series present worth analysis. This method uses a capital recovery factor which converts a zero time cost to an equivalent uniform end-of-year annual cost. The annual cost repays the initial expenditure with interest.

To derive the capital recovery factor, two relationships between present worth and future worth must be established. In the previous section, it was stated that future worth is equal to present worth compounded for n years at a specific compound interest rate, i.

$$FW = PW(1 + i)^n \qquad \text{Eq. 2.1}$$

The uniform series of end-of-year deposits that must be made for n years at compound interest to provide the required future sum can be expressed as:

$$R = FW[i/(1 + i)^n - 1] \qquad \text{Eq. 2.2}$$

To find the future series end-of-year payments that will just recover a present sum PW over n years with compound interest, the relationships in equations 2.1 and 2.2 are combined as follows:

$$R = PW[i(1 + i)^n/(1 + i)^n - 1] \qquad \text{Eq. 2.3}$$

This factor is referred to as the capital recovery factor. The value of n must be equal to the estimated service life of a material in order to make valid comparisons between materials. Thus, a short-lived material will have a larger capital recovery factor and the annual payments or annual cost will be larger.

To calculate the maintenance costs, the effect of inflation over the lifetime of the well must be considered. If A_1 is the first year maintenance cost, then any future maintenance cost is equal to:

$$A_n = A_1[1 + (t \cdot n)] \qquad \text{Eq. 2.4}$$

where t is the projected rate of inflation, and n is the number of years beyond the first year.

To calculate the total maintenance cost over the life of the well, n is made equal to the estimated service life minus one year and the following relationship used:

$$\frac{A_1 + A_n[1 + (t \cdot n)]}{2} \cdot [(n/f) + 1] \quad \text{Eq. 2.5}$$

where f is the frequency of maintenance. The factor [(n/f) + 1] is reduced to an integer. Thus, if it came out to be 3.67, a value of 3 would be used.

The total maintenance cost is divided by the service life to give an annual cost. This is then added to the total annual capital cost of drilling and casing to give a total annual cost for the well.

Comparing this cost with that of a carbon steel well will give the amount of money saved each year by using the alternative material. This cost difference is then divided by the annual amount of thermal energy provided by the well to find the annual savings per gigajoule.

CHAPTER 3. RESULTS AND DISCUSSION

I. COST COMPARISONS

The values and equations determined in Chapter 2 form the basis for comparisons of the total annual costs for geothermal wells constructed of various materials.

Examples of specific applications discussed in Appendix A will be used to determine the required well design, well depth, flow rate, water temperature, and energy demand. Where possible, actual case histories will be used to provide realistic values.

Annual residential heating and cooling loads for each region were based on a residence with a floor space of 186 m^2, (2000 ft^2) R-33 insulation for ceilings, R-19 insulation for walls and floors, double pane glass on all windows, and one infiltration change per hour.

Annual heating and cooling loads have been calculated for 24 select cities using degree-days and indoor temperature of 21.1°C (70°F) and an internal load of 1.47 KJ/sec (5000 BTU/hr)[24]. Annual heating loads for one acre of greenhouse were calculated using heat transfer coefficients of 17.6×10^{-4} and 16.3×10^{-4} joules/s.cm^2.°C (1.22 and 1.13 BTU/hr.ft^2. °F) for the roof and walls, respectively, and a -23°C (-9.4°F) design temperature. These loads were used to determine average loads for various systems in each region listed in Table 2.6. Also shown in Table 2.6 are the annual costs of steel wells for all systems.

For those applications which require process heating, the annual heating load will be the same in all regions since the load is not dependent on climate.

Certain applications require fluid temperatures that are found extractable only in five regions in the western United States. Thus, for cost comparisons involving these applications only the five western regions will be used.

For wells deeper than 610 m (2000 ft), larger drilling rigs are required and the costs listed in Table 2.1 are not applicable. For these wells, recent costs estimates for deep geothermal well drilling [27] will be used. Regional variations in deep drilling cost are assumed to be insignificant.

TABLE 2.6

ANNUAL COST OF STEEL WELLS (1980 DOLLARS)
ANNUAL ENERGY DEMAND (GIAGAJOULES)

FOR GEOTHERMAL SYSTEMS

System *	Western Mountain Ranges	Alluvial Basins	Columbia Lava Plateau	Colorado Plateau	High Plains	Glaciated Central Region	Unglaciated Central Region	Unglaciated Appala-chians	Glaciated Appala-chians	Coastal Plains
A-1	1,339 91	1,786 107	1,169 90	1,176 116	1,738 105	2,312 100	1,069 109	1,060 113	1,840 97	1,726 14
A-2	2,052 1,815	1,828 2,131	2,385 1,794	2,100 2,329	1,781 2,109	2,474 2,007	2,141 2,188	2,298 2,262	1,846 1,939	2,098 2,722
A-3	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332	68,419 20,332
B-1	918 374	820 307	903 359	820 277						
C-1	34,478 54,227	36,548 44,521	39,793 52,012	36,907 40,090			35,768 46,737			
C-2	10,781 49,850	11,512 40,927	10,536 47,806	9,931 36,854			10,673 42,960			9,227 114,053
D-1	24,605 2,475,241	24,605 2,032,141	24,605 2,373,750	24,605 1,829,898			24,605 2,134,687	24,605 1,611,776		24,605 1,339,544
E-1	35,299 10,391	37,529 8,941	40,609 10,445	37,765 8,052			36,767 8,572			
E-2	27,605 11,565	24,381 9,495	27,481 11,091	28,280 8,550			24,322 9,103	35,554 7,853		23,347 5,557
E-3	38,142 47,304	32,489 38,837	36,982 45,365	34,094 34,972			32,982 37,232			
E-4	32,530 26,984	34,072 22,153	33,454 25,877	31,028 19,949			30,227 21,238			
E-5	1,107 330	1,362 271	1,077 316	992 244			882 260			
F-1	29,448 9,041	29,729 9,041	33,880 9,041	31,505 9,041			30,519 9,041			
F-2	11,766 329,160	13,210 329,160	12,553 329,160	12,588 329,160			12,194 329,160			
F-3	229,687 907,300	257,863 907,300	264,257 907,300	245,730 907,300			238,053 907,300			
F-4	47,116 369,250	50,092 369,250	54,206 369,250	50,406 369,250			48,831 369,250			
F-5	188,462 474,750	200,322 474,750	223,133 474,750	201,618 474,750			195,325 474,750			
F-6	4,263,900 233,166	4,263,900 233,166	4,263,900 233,166	4,263,900 233,166			4,263,900 233,166			

*Letter-number code refers to second and third subheading in this section

A. Ground Water Geothermal Heat Pumps

1. Single Dwelling [28]

The following assumptions were used in calculating well costs for this application: One production well and one injection well are required. Diameter and depth of both wells are the same, 152 mm and 46 m (6 in and 150 ft). Flow rate is .5 l/s (8 gpm) and wellhead temperature is the average ground water temperature for each region. The type of aquifer is the most widespread type in each region.

Table 2.7 summarizes the results of the cost comparison for a single dwelling ground water geothermal heat pump system.

2. District Heating System [29]

Well design for this system is based on a 20-home module. One production well and one injection well of the same diameter 152 mm (6 in) and depth, 46 m (150 ft) are required. The production well delivers 6.3 l/s (100 gpm) of ambient temperature groundwater to heat pump units in each home. The injection well discharges hot or cold water to the aquifer which is assumed to be alluvium for all regions.

Table 2.7

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Ground Water Heat Pump Single Dwelling

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS	CPVC	PVC	SBR	FRPE[b]	FRPV[c]	RPM[c]	WOOD[h]	AC[d]	PC[e]
1	Sandstone	744 / 8.20	535 / 5.90	801 / 8.82	907 / 10.00	546 / 6.01	596 / 6.57			894 / 9.86	440 / 4.84
2	Alluvium	1114 / 10.45	854 / 8.02	1201 / 11.27	1328 / 12.46	910 / 8.54	977 / 9.17			1321 / 12.40	864 / 8.10
3	Basalt	635 / 7.08	428 / 4.78	690 / 7.70	795 / 8.86	436 / 4.86	485 / 5.41			786 / 8.77	407 / 4.54
4	Sandstone	636 / 5.46	423 / 3.63	693 / 5.95	801 / 6.88	430 / 3.69	481 / 4.13			792 / 6.80	415 / 3.56
5	Alluvium	1078 / 10.22	818 / 7.75	1166 / 11.05	1293 / 12.26	849 / 8.05	916 / 8.68			1286 / 12.19	845 / 7.59
6	Alluvium	1541 / 15.36	1333 / 13.29	1597 / 15.91	1703 / 16.98	1320 / 13.16	1370 / 13.66			1676 / 16.70	990 / 9.86
7	Sandstone	561 / 5.13	351 / 3.20	618 / 5.65	724 / 6.62	357 / 3.26	407 / 3.72			717 / 6.55	377 / 3.45
8	Metamorphic	531 / 4.69	324 / 2.86	587 / 5.19	692 / 6.12	332 / 2.94	381 / 3.36			682 / 6.03	310 / 2.74
9	Alluvium	1161 / 11.97	900 / 9.28	1249 / 12.88	1374 / 14.17	956 / 9.86	1024 / 10.56			1368 / 14.11	903 / 9.32
10	Demi-Con-Solidated	981 / 7.20	721 / 5.30	1069 / 7.86	1196 / 8.79	782 / 5.74	850 / 6.25			1183 / 8.69	631 / 4.64

Table 2.8

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Districe Heating with Ground Water Heat Pump

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS	CPVC	PVC	SBR	FRPE[b]	FRPV[c]	RPM[h]	WOOD[h]	AC[d]	PC[e]
1	Alluvium	1337 / .74	1087 / .60	1413 / .78	1538 / .84	1124 / .62	1187 / .65			1523 / .84	985 / .54
2	Alluvium	1172 / .55	922 / .43	1249 / .59	1373 / .64	955 / .45	1018 / .48			1363 / .64	902 / .42
3	Alluvium	1582 / .88	1332 / .74	1658 / .92	1783 / 1.00	1457 / .81	1520 / .85			1762 / .98	1100 / .61
4	Alluvium	1373 / .59	1122 / .48	1449 / .62	1573 / .67	1161 / .50	1223 / .53			1558 / .67	1003 / .43
5	Alluvium	1138 / .54	888 / .42	1214 / .58	1338 / .64	920 / .44	983 / .47			1329 / .63	885 / .42
6	Alluvium	1647 / .82	1397 / .70	1723 / .86	1848 / .92	1442 / .72	1505 / .75			1826 / .91	1141 / .57
7	Alluvium	1403 / .64	1152 / .53	1479 / .58	1603 / .73	1191 / .54	1254 / .57			1587 / .73	1018 / .47
8	Alluvium	1518 / .67	1268 / .56	1594 / .70	1719 / .76	1310 / .58	1373 / .61			1700 / .75	1076 / .48
9	Alluvium	1186 / .61	936 / .48	1262 / .65	1387 / .72	969 / .50	1032 / .53			1376 / .71	909 / .47
10	Alluvium	1374 / .51	1123 / .41	1450 / .53	1574 / .58	1162 / .43	1224 / .45			1327 / .49	1004 / .37

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

The results of the cost comparison for this system are summarized in Table 2.8.

3. Industrial or Commercial Process Heating [2]

For this system a 914 m (3000 ft) deep, 203 mm- (8 in-) diameter well supplies 20.5 l/s (325 gpm) of 38°C (100°F) water to a Templifier heat pump which increases the temperature of the water for process heating. An injection well of the same dimensions disposes cooled water into the aquifer which is the most permeable deep aquifer in each region.

Table 2.9 lists the results of the cost comparison of this application.

B. Downhole Heat Exchanger

1. Four-home module

Design factors for the DHE systems have been established in previous studies [16,25,30]. Only one 61 m (200 ft) well is required and flow rate is not a factor since there is no fluid production. The diameter of the casing is 203 mm (8 in) and the diameter of the borehole is 254 mm (10 in). The reservoir temperature used for this application is 66°C (151°F). Since only four regions contain shallow aquifers with this temperature, only those regions will be

Table 2.9

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Industrial Heat Pump

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS[g]	CPVC[gii]	PVC[g]	SBR	FRPE[b]	FRPV[c,g]	RPM[g]	WOOD	AC[d,g]	PC[e,g]
1	Sandstone					21726 / 1.068			17537 / .86		
2	Sandstone					21726 / 1.068			17537 / .86		
3	Sandstone					21726 / 1.068			17537 / .86		
4	Sandstone					21726 / 1.068			17537 / .86		
5	Sandstone					21726 / 1.068			17537 / .86		
6	Sandstone					21726 / 1.068			17537 / .86		
7	Sandstone					21726 / 1.068			17537 / .86		
8	Sandstone					21726 / 1.068			17537 / .86		
9	Sandstone					21726 / 1.068			17537 / .86		
10	Sandstone					21726 / 1.068			17537 / .86		

Table 2.10

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Downhole Heat Excahnger - 4 Dwellings

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS	CPVC[i]	PVC[f]	SBR[f]	FRPE[b]	FRPV[c]	RPM	WOOD	AC[d]	PC[e]
1	Sandstone	389 / 1.04				170 / .45	131 / .35	260 / .69	120 / .32	595 / 1.59	281 / .75
2	Alluvium	324 / 1.05				102 / .33	62 / .20	197 / .64	54 / .18	553 / 1.73	263 / .85
3	Basalt	380 / 1.23				161 / .52	122 / .40	252 / .82	112 / .36	596 / 1.91	281 / .91
4	Sandstone	332 / 1.20				110 / .40	71 / .26	206 / .75	63 / .23	541 / 1.95	281 / 1.01

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

considered. The aquifer will be the most common consolidated rock in the region except in the Alluvial Basins Region where it will be unconsolidated alluvium.

Table 2.10 lists the results of the cost comparisons.

C. Surface Heat Exchanger

1. District Heating System - 1000 buildings [16]

For this system, 1,000 homes are heated by exchange with 82°C (180°F) water supplied by two 203 mm (8 in), 610 m-(2000 ft-) deep wells at a rate of 31.5 l/s (500 gpm). 54°C (129°F) discharge water is disposed of through one injection well with the same dimensions as the production wells. The same four regions and types of aquifers used in the case of downhole heat exchangers will be used in this system.

Results of the cost comparison can be found in Table 2.11.

2. District Heating System - 125 buildings [17]

This system, proposed for Midland, S.D. requires one 152 mm (6 in) artesian well with a depth of 610 m (2000 ft) and a flow rate of 57.1 l/s (905 gpm). No injection wells are required. Wellhead temperature is 71°C (160°F), which is sufficient to heat 125 buildings using surface heat exchangers.

The four western regions will be used and the aquifer is the most typical artesian aquifer in each region.

Table 2.12 summarizes the cost comparison results.

D. Surface Heat Exchanger plus Heat Pump

1. District Heating System - 2,500 apartments

An economic analysis of geothermal district heating in the Paris Basin [31] showed that the optimum number of apartments is 2,500. Total flow requirement varies from 27.8 to 55.5 l/s (440 to 880 gpm) of 65°C (149°F) water. Well design for this system has been recently reported [32]. Due to the highly corrosive nature of the geothermal fluid (23,000 ppm NaCl), fiberglass casing was required. Well depth is 2,000 m (6562 ft), diameter is 203 mm (8 in).

Table 2.11

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: SHE - 1000-Building Heating System

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS[g]	CPVC[g,i]	PVC	SBR[g]	FRPE[b]	FRPV[c,g]	RPM[g]	WOOD	AC[d,g]	PC[e]
1	Sandstone					9962 / .18			10425 / .19		12056 / .22
2	Alluvium					14290 / .32			13686 / .31		16960 / .38
3	Basalt					12334 / .24			14352 / .28		13555 / .26
4	Sandstone					11918 / .30			12604 / .31		13891 / .35
7	Sandstone					14057 / .30					

Table 2.12

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: SHE - 125-Building Heating System

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS[f,g]	CPVC[g]	PVC[f,g]	SBR[f,g]	FRPE[b]	FRPV[c,g]	RPM[f,g]	WOOD[h]	AC[d]	PC[e]
1	Sandstone					3724 / .075					4749 / .095
2	Alluvium					4780 / .117					6312 / .154
3	Basalt					3640 / .076					4741 / .100
4	Sandstone					3261 / .088					4890 / .133
7	Sandstone					4152 / .097					6014 / .140

Table 2.13

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: SHE & Heat Pump - Apartment Complex Heating

Basis of Comparison: Type 304 Stainless Steel

Region[a]	Aquifer	ABS[g]	CPVC[g,i]	PVC[g]	SBR[g]	FRPE[b]	FRPV[c,g]	RPM[g]	WOOD[g]	AC[d,g]	PC[e,g]
1	Sandstone					2485 / .0010					
2	Sandstone					2485 / .0012					
3	Sandstone					2485 / .0010					
4	Sandstone					2485 / .0014					
7	Sandstone					2485 / .0012					
8	Sandstone					2485 / .0015					
10	Sandstone					2485 / .0016					

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

Cost comparisons, based on type 304 stainless steel casing and screen are shown in Table 2.13.

E. Direct Heating

1. 15-Acre Greenhouse Complex [17]

For this system, a single 203 mm (8 in) injection well could handle up to three 203 mm (8 in) production wells. Assuming a well depth of 457 m (1500 ft), a wellhead temperature of 93°C (200°F) and a flow of 31.5 l/s (500 gpm) per well, this system would supply a 15-acre greenhouse complex which is the optimum size for such a system. Injection temperature is 32°C (90°F).

A permeable aquifer is used in each of the four western regions due to the large volume of water required.

Table 2.14 lists the results of the cost comparisons for this system.

2. Two-Acre Greenhouse [17]

This system would require eleven 152 mm (6 in), 61 m- (200 ft-) deep production wells supplying a total of 250 l/s (3,960 gpm) of 43°C (109°F) fluid which directly heats the greenhouse and is disposed of at a temperature of 32°C (90°F) through eleven injection wells of the same dimensions as the production wells.

Due to the lower temperature requirements, this system can be used in seven regions. An alluvial aquifer is assumed for each region except Region 7.

Results of the cost comparison for a this system are shown in Table 2.15.

3. Municipal Heating System - 283 homes [33]

District heating with 77°C (171°F) geothermal fluid has been done successfully for over 40 years in Boise, Idaho. A system comprised of a 305 mm (12 in), 610 m- (2000 ft-) deep well supplying 63.1 l/s (1,000 gpm) of 77°C (171°F) water and a return well of the same dimensions could heat 283 homes.

Table 2.14

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: 15 - Acre Greenhouse

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS[g]	CPVC[g,i]	PVC[g]	SBR[g]	FRPE[b]	FRPV[c,g]	RPM[g]	WOOD	AC[d,g]	PC[e]
1	Sandstone					9458 / .87			9606 / .88	12636 / 1.16	
2	Alluvium					14088 / 1.58			13026 / 1.46	17692 / 1.98	
3	Basalt					11633 / 1.11			13550 / 1.30	14134 / 1.35	
4	Sandstone					16888 / 2.10			11824 / 1.47	14510 / 1.80	
7	Sandstone					8954 / 1.04					

Table 2.15

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: 2 - Acre Greenhouse

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS	CPVC	PVC	SBR	FRPE[b]	FRPV[c]	RPM[h]	WOOD[h]	AC[d]	PC[e]
1	Alluvium	15258 / 1.32	10557 / .91	17510 / 1.52	19607 / 1.70	13298 / 1.15	14732 / 1.27			19647 / 1.70	11921 / 1.03
2	Alluvium	12909 / 1.47	8208 / .86	15160 / 1.59	17238 / 1.81	10885 / 1.15	12319 / 1.30			17358 / 1.83	10774 / 1.14
3	Alluvium	14038 / 1.27	9405 / .84	16257 / 1.47	18324 / 1.65	12195 / 1.10	13608 / 1.22			18268 / 1.65	8985 / .81
4	Alluvium	15752 / 1.84	11051 / 1.29	18004 / 2.10	20101 / 2.35	13802 / 1.61	15236 / 1.78			20125 / 2.35	12160 / 1.42
7	Sandstone	11630 / 1.28	6929 / .76	13881 / 1.53	15979 / 1.75	12597 / 1.38	11127 / 1.22			15990 / 1.75	7810 / .86
8	Alluvium	22249 / 2.83	17548 / 2.24	24500 / 3.12	26598 / 3.38	20359 / 2.60	21793 / 2.78			26568 / 3.38	17588 / 2.24
10	Alluvium	11306 / 2.04	6605 / 1.18	13557 / 2.44	15661 / 2.82	9359 / 1.69	10793 / 1.94			15682 / 2.82	7700 / 1.33

Table 2.16

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Direct Heating - 283 Homes

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS[g]	CPVC[g,i]	PVC[g]	SBR[f,g,i]	FRPE[b,i]	FRPV[c,g]	RPM[g]	WOOD	AC[d,g]	PC[e]
1	Sandstone					8558 / .181			11666 / .247	12007 / .254	
2	Alluvium					6124 / .158			9480 / .244	14609 / .376	
3	Basalt					8119 / .179			11204 / .247	11977 / .264	
4	Sandstone					6174 / .177			9410 / .269	12227 / .350	
7	Sandstone					4890 / .120			8110 / .199	10668 / .262	

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

Results of the cost comparisons are shown in Table 2.16.

4. Educational Institution [30]

The Oregon Institute of Technology campus is heated directly by 88°C (190°F) geothermal fluid. It consists of eight buildings covering approximately 51,095 m^2 (549, 782 ft^2) of floor space. Three hot water wells vary in depth from 393 to 549 m (1288 to 1800 ft) and in diameter from 356 mm (14 in) at the top to 203 mm (8 in) at the bottom with casing varying from 305 mm to 152 mm (12-6 in) in diameter. These wells can be individually pumped up to 28.4 l/s (450 gpm). Up to two wells are used at one time. The water is discharged at 52°C (126°F) into a lake.

The results of the cost comparisons are listed in Table 2.17.

5. Municipal Swimming Pool [30]

This system uses one production well 152 mm (6 in) in diameter and 75 m (246 ft) deep to deliver 1.6 l/s (25 gpm) of 93°C (200°F) water to heat a large municipal swimming pool. The water is then discharged into the city storm sewer system.

Table 2.18 lists the results of the cost comparisons for this system.

F. Direct Process Heating

1. Onion Dehydration [17].

Cost analysis for this application assummed two 203-mm (8 in) wells, 610-m (2000 ft) deep delivering a total of 56.8 l/s (900 gpm) of 110°C (230°F) water, and one 203-mm (8 in-), 305 m-(1000 ft-) deep injection well disposing fluid of 77°C (171°F).

Results of the cost comparison are presented in Table 2.19.

2. Alfalfa Drying [17]

This system uses one production well 203 mm (8 in) in diameter and 457 m (1500 ft) deep and one injection well of the same diameter but 152 m (500 ft) deep. The production

Table 2.17

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Heating Educational Institution

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS[f,g]	CPVC[g,i]	PVC[f,g]	SBR[f,g,i]	FRPE[b,f,i]	FRPV[c,f]	RPM[f,g]	WOOD	AC[d,g]	PC[e]
1	Sandstone					2054 / .076			3816 / .149		13437 / .498
2	Alluvium					5713 / .258			7563 / .360		17920 / .809
3	Basalt					2836 / .110			4549 / .185		13829 / .534
4	Sandstone					2146 / .108			5478 / .290		14149 / .709
7	Sandstone					936 / .040			2748 / .125		12780 / .580

Table 2.18

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Swimming Pool Heating

Basis of Comparison: API 5L Grade A Steel

Region[a]	Aquifer	ABS[f]	CPVC	PVC[f]	SBR[f]	FRPE[b,f]	FRPV[c,f]	RPM[f,h]	WOOD[h]	AC[d]	PC[e]
1	Sandstone		201 / .61			225 / .68				517 / 1.56	370 / 1.12
2	Alluvium		389 / 1.44			466 / 1.72				751 / 2.79	602 / 2.22
3	Basalt		412 / 1.30			221 / .70				723 / 2.28	369 / 1.17
4	Sandstone		360 / 1.47			209 / .86				679 / 2.78	386 / 1.58
7	Sandstone		102 / .36			152 / .53			423 / 1.49		313 / 1.10

Table 2.19

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Onion Dehydration

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS	CPVC[g,i]	PVC[f,g]	SBR	FRPE[b]	FRPV[c,f,g]	RPM[f,g]	WOOD	AC[d,g]	PC[e]
1	Sandstone	7366 / .81				4985 / .55			2571 / .28		10542 / 1.17
2	Alluvium	8362 / .92				6154 / .68			3812 / .42		12054 / 1.33
3	Basalt	9106 / 1.00				7283 / .81			4835 / .53		11792 / 1.30
4	Sandstone	8747 / .96				6686 / .74			4293 / .47		12105 / 1.34
7	Sandstone	7688 / .85				5381 / .63			2974 / .33		10675 / 1.18

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

well supplies 18.9 l/s (300 gpm) of 104°C (219°F) fluid to dry 1,452 kgs/hr (3200 lb/hr). of alfalfa. Return fluid temperature is 79°C (174°F).

Results of the cost comparisons are summarized in Table 2.20.

3. Beet Sugar Plant [17]

For this system, thirty-two production wells and sixteen injection wells are required. Twenty-six production wells are in operation delivering a total of 410 l/s (6,500 gpm) of 149°C (300°F) fluid. Thirteen injection wells dispose of 102°C (216°F) fluid. The diameter and depth of all wells is 203 mm (8 in) and 305 m (1000 ft) respectively.

Cost comparison results are listed in Table 2.21.

4. Salt Evaporation [17]

This system assumes five production wells and three injection wells of 203 mm (8 in) diameter and 305 m (1000 ft) in depth. Four of the production wells supply a total of 63.1 l/s (1,000 gpm) of 149°C (300°F) water to flash steam units. Discharge water temperature of 64°C (147°F) is returned to the aquifer through two of the injection wells.

Results of the cost comparisons are shown in Table 2.22.

5. Tomato Paste Plant [17]

For this system, twenty-one production wells and eleven injection wells are required. Diameter and depth of the wells are the same, 203 mm (8 in) and 305 m (1000 ft). Seventeen of the production wells are used to supply a total of 268.1 l/s (4,250 gpm) of 149°C (300°F) fluid to flash steam units. Nine injection wells dispose of 71°C (160°F) fluid.

Table 2.23 lists the results of the cost comparisons of this system.

6. Pulp and Paper Plant [34]

This system uses twenty six production wells 203 mm (8 in) in diameter and 1,829 m (6000 ft) deep delivering a total of 823 l/s (13,043 gpm) of 121°C (250°F) water.

Injection wells of the same number and dimension as the production wells dispose of 63.5°C (146°F) brine to a permeable aquifer.

Table 2.24 lists the cost comparison results.

Table 2.20

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Alfalfa Drying

Basis of Comparison: API Grade L-55 Steel

Region[a]	Aquifer	ABS	CPVC[g,i]	PVC[f,g]	SBR[f,g]	FRPE[b,f]	FRPV[c,f,g]	RPM[f,g]	WOOD	AC[d,g]	PC[e]
1	Sandstone	2997 / .004				2000 / .006			1044 / .003		4212 / .013
2	Alluvium	4463 / .014				3798 / .012			2857 / .009		6149 / .019
3	Basalt	2890 / .009				1934 / .006			950 / .003		3727 / .011
4	Sandstone	3542 / .011				2680 / .008			1718 / .005		4837 / .015
7	Sandstone	3116 / .010				2158 / .007			4265 / .013		1191 / .004

Table 2.21

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Beet Sugar Plant

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS[f]	CPVC[f,g,i]	PVC[f,g]	SBR[f,g]	FRPE[b,f]	FRPV[c,f]	RPM[f]	WOOD	AC[d,g]	PC[e]
1	Sandstone					38405 / .042			42634 / .047		82222 / .091
2	Alluvium					79846 / .088			79625 / .088		120016 / .132
3	Basalt					56339 / .062			55201 / .061		91971 / .101
4	Sandstone					51669 / .057			55147 / .061		94414 / .104
7	Sandstone					41501 / .046			44286 / .049		83264 / .092

Table 2.22

Savings Per Year (1980 Dollars)

Savings/ Gigajoule/Year

Application: Salt Evaporation

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS	CPVC[g]	PVC[g]	SBR[f,g]	FRPE[b]	FRPV[c]	RPM	WOOD	AC[d,g]	PC[e]
1	Sandstone	12283 / .033				7879 / .021	8657 / .023	10430 / .028	8458 / .011		13232 / .036
2	Alluvium	18684 / .051				13577 / .037	15016 / .041	16874 / .046	14859 / .040		23622 / .064
3	Basalt	14866 / .040				11556 / .029	11355 / .030	12978 / .035	11096 / .030		15283 / .041
4	Sandstone	14851 / .040				10599 / .031	11240 / .031	12996 / .035	11032 / .030		19367 / .052
7	Sandstone	12636 / .034				8513 / .023	9028 / .024	8498 / .023	8715 / .024		17079 / .046

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

Table 2.23
Savings Per Year (1980 Dollars)
Savings/ Gigajoule/Year

Application: Tomato Paste Plant

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS	CPVC[g,i]	PVC[f,g]	SBR[f,g]	FRPE[b,f]	FRPV[c,f]	RPM[f]	WOOD	AC[d,g]	PC[e]
1	Sandstone	48718 / .103				31513 / .066			34695 / .073		52929 / .111
2	Alluvium	74101 / .158				54353 / .114			60952 / .128		94436 / .199
3	Basalt	58959 / .124				52534 / .111			45516 / .096		67437 / .142
4	Sandstone	58899 / .124				43289 / .089			45253 / .095		77469 / .163
7	Sandstone	50134 / .106				34053 / .072			35749 / .075		68317 / .144

Table 2.24
Savings Per Year (1980 Dollars)
Savings/ Gigajoule/Year

Application: Pulp and Paper Plant

Basis of Comparison: API Grade K-55 Steel

Region[a]	Aquifer	ABS[g]	CPVC[g,i]	PVC[g]	SBR[f,g]	FRPE[b]	FRPV[c,g]	RPM[g]	WOOD	AC[d,g]	PC[e,g]
1	Sandstone					1228600 / 5.27			1220900 / 5.24		
2	Sandstone					1228600 / 5.27			1220900 / 5.24		
3	Sandstone					1228600 / 5.27			1220900 / 5.24		
4	Sandstone					1228600 / 5.27			1220900 / 5.24		

(a) Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B
(b) Fiberglass Reinforced Epoxy Casing
(c) Fiberglass Reinforced Vinylester Casing
(d) Asbestos Cement Casing
(e) Polymer Concrete Casing
(f) Application exceeds maximum temperature limit of casing for both production and injection wells
(g) Application exceeds maximum depth limit of casing
(h) Required diameter is too small for this type of casing
(i) Required diameter is too large for this type of casing

II. ECONOMIC IMPACT

A. Savings Due to Nonmetallic Wells

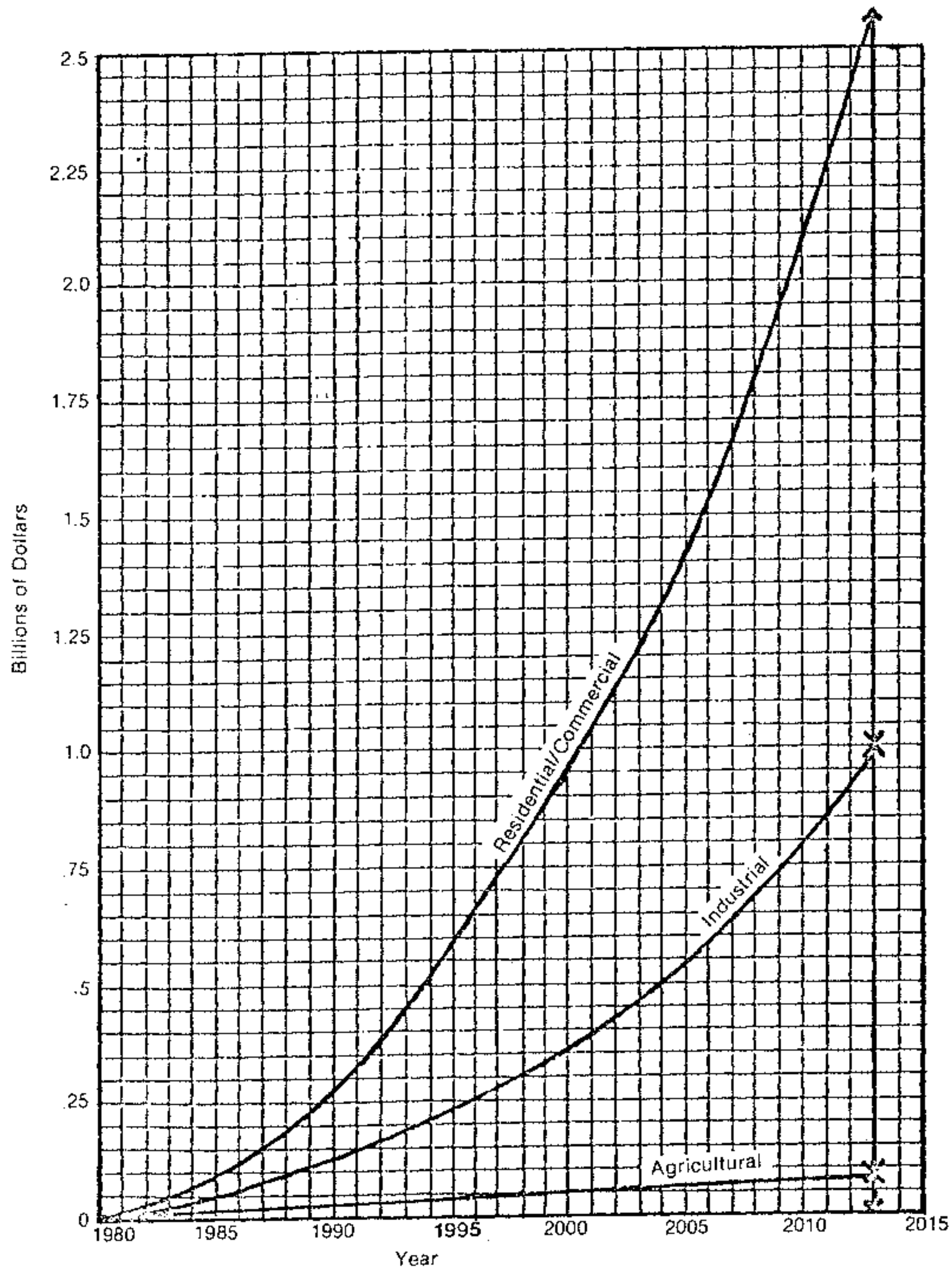
The economic impact of using nonmetallic materials in low-temperature geothermal well construction depends on the extent to which low-temperature geothermal resources are used. The Department of Energy/Division of Geothermal Energy nonelectric geothermal development scenario was used to calculate thermal power on-line from the years 1981 to 2013 for residential/commercial, industrial, and agricultural applications in four western regions and one eastern region.[35] The data for the eastern region was not used in the present study since its excessive well depths prohibit use of nonmetallic casing. Thermal power data for the remaining four regions were combined with data on savings per gigajoule from the cost comparisons to arrive at annual savings for the three use categories in the four regions. Fiberglass reinforced epoxy was selected as the nonmetallic casing material for all applications in the four regions due to its high strength and temperature resistance. Average savings per gigajoule were used based on the savings resulting from the use of fiberglass reinforced epoxy in actual geothermal systems in each region. The savings were inflated at a 12 percent compound rate and cumulated over the 33 years to arrive at a total savings. The results of these calculations are shown in Table 3.1 and Figure 3.1.

TABLE 3.1
Total Savings From 1981-2013 Due To The Use Of Fiberglass Reinforced Epoxy Materials In Wells For Nonelectric Geothermal Systems

(10^6 dollars)

Region	Residential & Commercial	Industrial	Agricultural
Western Mt. Range	331.22	85.36	8.24
Alluvial Basins	680.41	303.21	60.52
Columbia Lava Plateau	387.65	394.63	1.46
Unglaciated Central Region	218.06	149.0678	0.78
Total U.S.	1,617.34	932.27	71.00

Figure 3.1 Cumulative Savings Resulting From the Use of Fiberglass Reinforced Epoxy Well Casing for Low-Temperature Geothermal Systems



The use of nonmetallic materials in wells for ground-water heat pump systems can result in considerable savings depending on the number of new wells drilled for this purpose. Since ground-water heat pumps are relatively new and not well-established on the market, it is impossible to make accurate market projections over the next 33 years. Even if these projections were available, there would be no way of estimating the percentage of heat pump installations that would already have an existing well.

A more meaningful estimate was obtained by using the results of water well contractor surveys.[36,37] In 1980 there will be about 900,000 new water wells drilled in the United States. Based on housing market projections[38], this amount will increase by an average of 45,000 new wells per year until 1990, after which it will remain at 1,350,000 new wells per year until 2013. For each region, a certain percentage of the total number of wells was calculated from a recent contractor survey.[36] Since nonmetallic wells are almost exclusively drilled with rotary drilling rigs, the percentage of the total wells in each region that are rotary-drilled was calculated from the results of another contractor survey.[37] By multiplying the total number of wells in any year by the first percentage then multiplying this result by the second percentage, the total number of rotary-drilled wells in each region can be obtained. This figure represents the maximum number of new wells in each region that could be constructed of nonmetallic materials. There are no means of predicting how many of these wells would be used for ground-water heat pump systems. However, if a low value of .1% and a high value of 1% are assumed, it is possible to obtain a range of potential savings for each region and for the nation as a whole.

The results of the above calculations for domestic and commercial wells in all regions for the year 1981 are shown in Table 3.2. The annual savings per well were based on the assumption that 5 percent of the heat pump units were used in district heating systems, PVC was used for supply wells, and fiberglass reinforced epoxy was used for injection wells. The cumulative savings from 1981 to 2013 for all wells used for heat pump systems in each region are shown in Table 3.3. Although it was possible to calculate the number of rotary-drilled agricultural wells in each region, the annual savings per well could not be calculated due to the absence of data on actual agricultural heat pump systems.

TABLE 3.2

ANNUAL SAVINGS RESULTING FROM THE USE OF NONMETALLIC MATERIALS IN WELLS FOR DOMESTIC AND COMMERCIAL HEAT PUMP SYSTEMS (1981)

*Region	of Total New Wells	No. of New Wells	% Rotary-Drilled Domestic/Commercial	No. Rotary-Drilled Domestic/Commercial	No. Heat Pump Wells Assuming .1%	Annual Savings Per Well	Total Annual Savings	No. Heat Pump Wells Assuming 1%	Total Annual Savings
1	3.629	34,294	23.06	7,908	8	$394	$3,151	79	$ 31,112
2	4.607	43,536	23.02	10,022	10	592	5,924	100	59,238
3	1.264	11,945	23.135	2,752	3	343	1,029	28	9,607
4	1.0335	9,767	22.78	2,225	2	335	670	22	7,376
5	5.306	50,142	41.89	21,004	21	566	11,883	210	118,833
6	31.2405	295,223	29.61	87,416	87	820	71,360	874	716,883
7	15.59	147,325	35.95	52,963	53	297	15,727	530	157,268
8	10.469	98,932	27.612	27,317	27	285	7,698	273	77,834
9	10.65	100,643	7.602	7,650	8	618	4,942	77	47,568
10	16.211	153,194	41.412	63,441	63	529	33,323	634	335,342
TOTAL U.S.		945,000		282,698	283		$155,707	2,827	$1,561,062

TOTAL ANNUAL SAVINGS
FOR U.S. ASSUMING .1%: $155,707

TOTAL ANNUAL SAVINGS
FOR U.S. ASSUMING 1% : $1,561,062

*Numbers refer to Ground Water Regions illustrated in Fig. 5 of Appendix B

TABLE 3.3
Cumulative Savings From 1981-2013 Due To The Use Of Nonmetallic Materials In Wells For Heat Pump Systems
(10^6 dollars)

Region	Residential & Commercial	Industrial
Western Mt. Ranges	$ 238.46 *	$ 12.33
	23.85 **	1.23
Alluvial Basins	472.57	15.62
	47.26	1.56
Columbia Lava Plateau	69.87	4.31
	6.99	.43
Colorado Plateau	56.01	3.47
	5.60	.35
High Plains	945.06	32.75
	9.45	3.28
Glaciated Central Region	5,700.88	136.34
	570.09	13.63
Unglaciated Central Region	1,159.11	82.59
	115.91	8.26
Unglaciated Appalachians	564.69	42.59
	56.47	4.26
Glaciated Appalachians	142.82	4.52
	14.28	.45
Coastal Plain	2,627.40	98.92
	262.74	9.90
Total U.S.	$11,976.87	$433.44
	1,197.69	43.34

*Top figure assumes 1% of rotary-drilled wells
**Bottom figure assumes .1% of rotary-drilled wells

B. Savings in Energy Consumption During Manufacturing

Any economic comparison between metallic and nonmetallic materials would be incomplete without considering the amount of energy required to manufacture a product. Steel manufacturing is more energy intensive than the manufacturing of plastics and other nonmetallics due primarily to the lighter weight of most nonmetallic products and secondarily to lower process heating requirements for the manufacture of some nonmetallic products. In the case of plastics, part of the energy is in the resin itself and is, for all practical purposes, used up. Thus, for a metric ton of plastic resin, approximately 44.74 GJ (42.41 million BTU) are used compared with 39.55 GJ (37.49 million BTU) for a ton of steel. During pipe manufacturing, an additional 97.70 GJ (92.61 million BTU) for plastic and 54.20 GJ (51.41 million BTU) for steel are required for each ton. However, in the final analysis, approximately four times as much energy is required to manufacture steel pipe than plastic pipe due to its greater weight.

By using an average well casing length per gigajoule in the geothermal systems in the western regions and an average casing length per well in the heat pump systems, a total length of 1.4127×10^7 meters of casing will be required from 1981 to 2013. The weight of this amount of casing is 75643.5 tons and 481327 tons for plastic and steel, respectively. The energy required to manufacture this casing is 10,774,600 GJ for plastic and 45,124,406 GJ for steel. Thus, the energy saved in manufacturing plastic casing is 34,349,806 GJ or the equivalent of 5.87 million barrels of oil.

NOTES ON UNITS

The geothermal community is an international one, thus all units are given in the International System (SI) with English (Engineering) in parenthesis, i.e. 160°C (140°F). Every attempt was made to use the same number of significant figures in both systems. Thus, for example, 150°C would be converted to 302°F when used as an exact number (three significant figures), and to 300°F when used as an approximate number (two significant figures).

The following English and International (SI) relationships and abbreviations were used:

English Engineering	International System (SI)
1 pound mass (lb)	= 0.4536 kilograms (kg)
1 foot-pound per inch (ft-lb/in)	= 0.054 kilogram-meters per centimeter (kg-m/cm)
1 ton (short = 2,000 lb)(tn)	= 0.9072 tonne (metric = 1,000 kg)(t)
1 ounce (oz)	= 28.35 grams (g)
1 pound per square foot (psf)	= 4.882 kilograms per square meter (kg/m^2)
1 pound per square inch (psi)	= 0.0703 kilograms per square centimeter(kg/cm^2)
1 pound per cubic inch (pci)	= 0.00277 kilograms per cubic centimeter(kg/cm^3)
1 mile (mi)	= 1.609 kilometer (km)
1 foot (ft)	= 0.3048 meters (m)
1 inch (in)	= 2.540 centimeters (cm)
1 gallon (gal)	= 3.785 liters (l)
1 gallon per minute (gpm)	= 0.06308 liter per second (l/s)
1 ton per hour (T/hr)	= .252 kilograms per second (kg/s)
1 British thermal unit (BTU)	= 1055 Joules (J)
	= 1.055 kilo Joules (kJ)
British thermal unit per hour (BTU/hr)	= 0.2930 watts (w)
1 acre (A)	= 0.4047 hectares (ha)
	= 4047 square meters (m^2)
*1 degree Fahrenheit (°F)	= 1.8 [degree celcius (°C)] + 32°
1°F/mile	= 0.345°C/km
1 British thermal unit per hour per foot per degree Fahrenheit (BTU/hr.Ft.°F)	= 0.0172958 Joules per second per centimeter per degree celcius (J/s.cm.°C)

10^{-6} = micro (u)
10^{-3} = milli (m)
10^{-2} = centi (c)
10^{3} = kilo (k)
10^{6} = mega (M)
10^{9} = giga (G)

*If only a change in temperature is required, then F° = 1.8 x (Δ C°)

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