ISSN 0276-1084

Vol. 18, No. 1

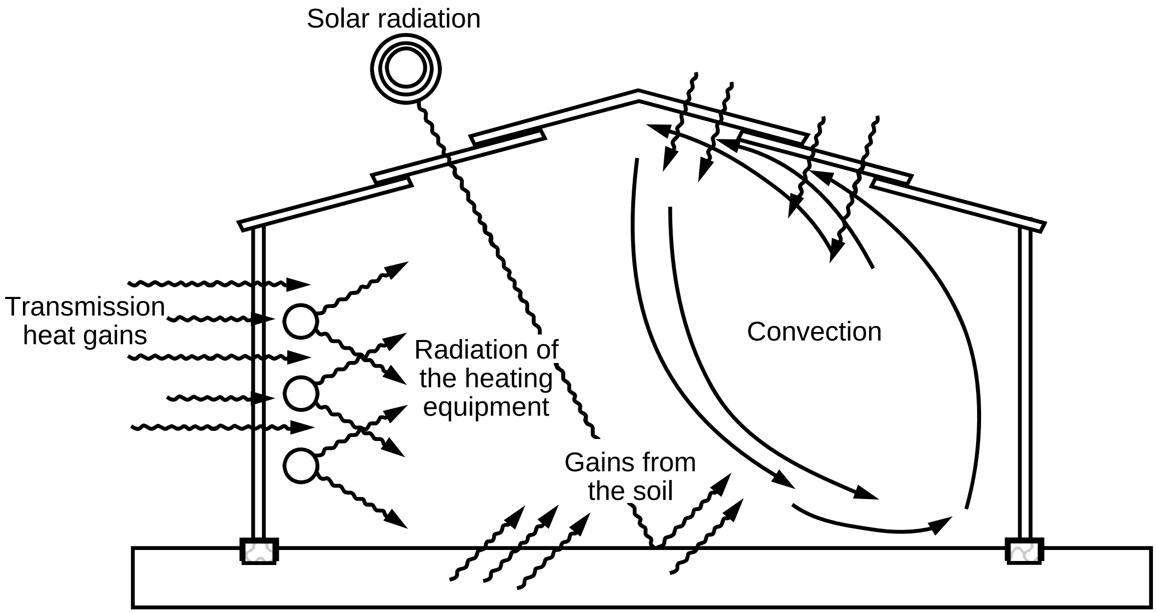
JANUARY 1997

GEO-HEAT CENTER

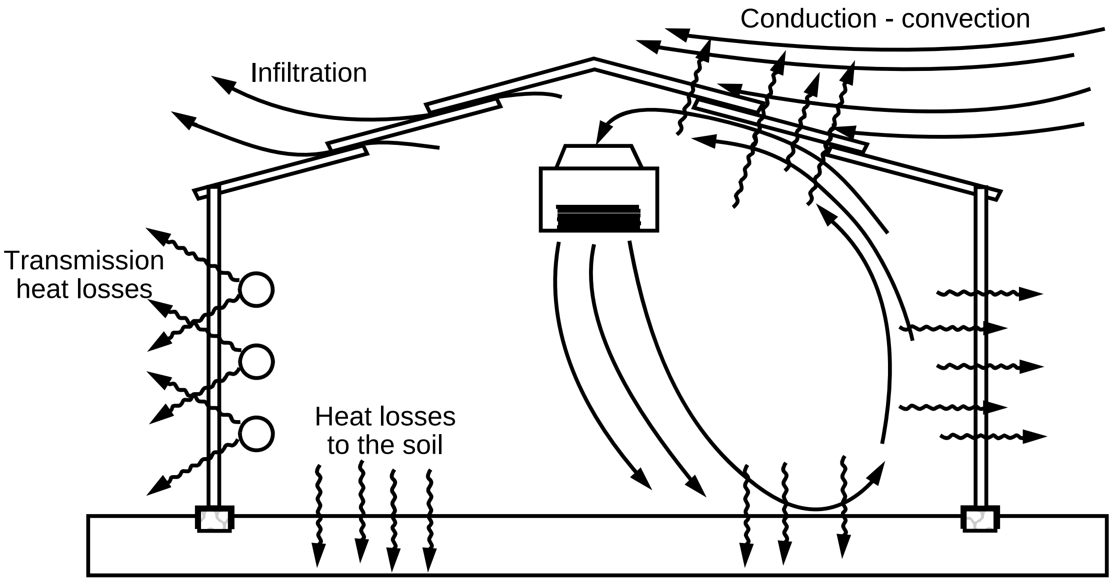
Quarterly Bulletin

OREGON INSTITUTE OF TECHNOLOGY -KLAMATH FALLS, OREGON 97601-8801
PHONE NO. (541) 885-1750

Factors Influencing Greenhouse Heating



HEAT GAINS



HEAT LOSSES

Vol. 18, No. 1 January 1997

GEO-HEAT CENTER QUARTERLY BULLETIN

ISSN 0276-1084

A Quarterly Progress and Development Report
on the Direct Utilization of Geothermal Resources

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Correction: Volume and number on the cover of our last Bulletin should have been Vol. 17, No. 4.

PUBLISHED BY

GEO-HEAT CENTER
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All articles for the Bulletin are solicited. If you wish to contribute a paper, please contact the editor at the above address.

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FUNDING

The Bulletin is provided compliments of the Geo-Heat Center. This material was prepared with the support of the U.S. Department of Energy (DOE Grant No. DE-FG07-90ID13040). However, any opinions, findings, conclusions, or recommendations expressed herein are those of the authors(s) and do not necessarily reflect the view of USDOE.

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FOSSIL FUEL-FIRED PEAK HEATING FOR GEOTHERMAL GREENHOUSES

Kevin Rafferty
Geo-Heat Center

INTRODUCTION

Greenhouses are a major application of low-temperature geothermal resources. In virtually all operating systems, the geothermal fluid is used in a hot water heating system to meet 100% of both the peak and annual heating requirements of the structure. This strategy is a result of the relatively low costs associated with the development of most U.S. geothermal direct-use resources and past tax credit programs which penalized systems using any conventional fuel sources.

Increasingly, greenhouse operations will encounter limitations in available geothermal resource flow due either to production or disposal considerations. As a result, it will be necessary to operate additions at reduced water temperatures reflective of the effluent from the existing operations. Water temperature has a strong influence on heating system design.

Greenhouse operators tend to have unequivocal preferences regarding heating system equipment. Many growers, particularly cut flower and bedding plant operators, prefer the "bare tube" type heating system. This system places small diameter plastic tubes under the benches or adjacent to the plants. Hot water is circulated through the tubes providing heat to the plants and the air in the greenhouse. Advantages include the ability to provide the heat directly to the plants, low cost, simple installation and the lack of a requirement for fans to circulate air. The major disadvantage of the system is poor performance at low (<140°F) water temperatures, particularly in cold climates. Under these conditions, the quantity of tubing required to meet the peak heating load is substantial. In fact, under some conditions, it is simply impractical to install sufficient tubing in the greenhouse to meet the peak heating load.

Forced-air heating equipment (unit heaters, fan coil units, etc.) is very effective at low temperature operation. Unfortunately, many growers strongly resist using it. In these cases, the use of cascaded geothermal fluid to provide a portion of the heating requirements (base load) along with a conventionally-fueled peak heating system may be an effective strategy.

Due to temperature occurrences in most western geothermal locations, a base load system (geothermal) designed for approximately 60% of the peak load can actually meet 95+% of the annual eating requirements. As a result, a facility with limited geothermal flow can expand, use the heating system of choice and still achieve substantial energy savings with a base load/peak load heating system design. In addition, the fossil-fueled peak load system offers a no-cost emergency backup in the event of a failure in the geothermal system.

CONVENTIONAL GREENHOUSE HEATING SYSTEMS

Conventional greenhouse heating systems can take a wide variety of configurations (unit heater, fan coil unit, bare tube, finned pipe, etc.). Two system types, however, are most common: fan coil and bare tube. The fan coil heating units, as the name implies, include a fan for moving the air and a coil or heat exchanger for transferring heat from the water to the air. Several designs are available with some off-the-shelf units optimized for performance at low (<120°F) temperatures. Custom designed units are also sometimes used.

Bare tube systems consist of a large quantity of bare tubing, usually of polyethylene, polybutylene or EPDM, distributed throughout the greenhouse. Bare tube systems, in comparison to fan coil systems, are characterized by low equipment cost and zero fan energy consumption and simple installation practices. This makes the bare tube system especially attractive to greenhouse growers. The tubing system permits do-it-yourself installation, another feature attractive to developers. At low water temperature, bare tube systems require substantial quantities of tubing to meet 100% of the peak heating requirement in cold climates. Figure 1 presents system costs for a 1-acre house in a moderately cold (0°F outside design temperature) climate.

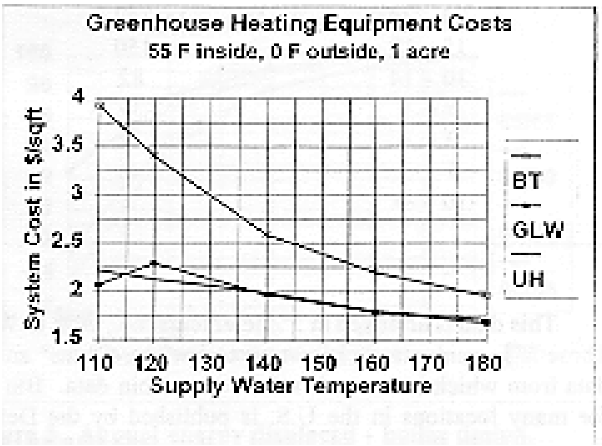

Figure 1. Greenhouse heating equipment costs.

It is apparent that the low-temperature unit heater (GLW) and the standard unit heater (UH) systems are more capable of economically dealing with low supply water temperatures than the bare tube system (BT). The reason for the high costs of the bare tube system at low temperatures is best illustrated with an example. Again using the 1-acre house of Figure 1, at a supply water temperature of 180°F, 106,000 feet of tubing would be required to meet the peak load. At a 110°F supply water temperature, this figure is 397,000 ft. This means that for the example greenhouse, tubes would have to be spaced at intervals of less than 1 1/2 inches (over the entire floor area) to meet the load at the lower temperature.

CLIMATE CONSIDERATIONS

The rationale behind using different base load and peak load heating systems lies partly in the annual temperature profile.

Table 1. Annual Temperature Occurrences (Bin Data) Klamath Falls, OR

Outside Temperature (°F)	Hours/Year
95 - 99	1
90 - 94	39
85 - 89	124
80 - 84	235
75 - 79	313
70 - 74	373
65 - 69	468
60 - 64	551
55 - 59	658
50 - 54	783
45 - 49	826
40 - 44	931
35 - 39	1044
30 - 34	1132
25 - 29	675
20 - 24	352
15 - 19	150
10 - 14	82
5 - 9	39
0 - 4	17
-5 - -1	6
-10 - -6	2

This data is arranged in 5° increments (i.e., 70° F to 74° F). These 5° increments are known as temperature "bins" and the data from which it comes is referred to as bin data. Bin data for many locations in the U.S. is published by the Defense Department in Engineering Weather Data, AFM 88-29, 1978.

The rate at which heat must be supplied to a structure (Btu/hr) to offset heat loss is directly related to the temperature difference between the outside air and the temperature inside the structure. The so-called peak load is calculated at an outside temperature referred to as the design outside temperature. This is a value below which only 1% of the hours in a typical winter occur. Conventional practice in the U.S. for geothermal systems is to design the system for 100% of the peak load.

The amount of energy required to heat a building (on annual basis) is determined by the number of hours occurring at outside temperatures less than the temperature maintained in the structure. The quantity of annual energy required at a particular temperature bin is determined by the number of hours at that bin and the temperature difference between it and the inside temperature of the structure. Summing the number of hours at various outside temperatures permits the development of a cumulative heating requirement curve similar to that in Figure 2. This particular plot was developed for an inside temperature of 60° F using the weather data from Table 1.

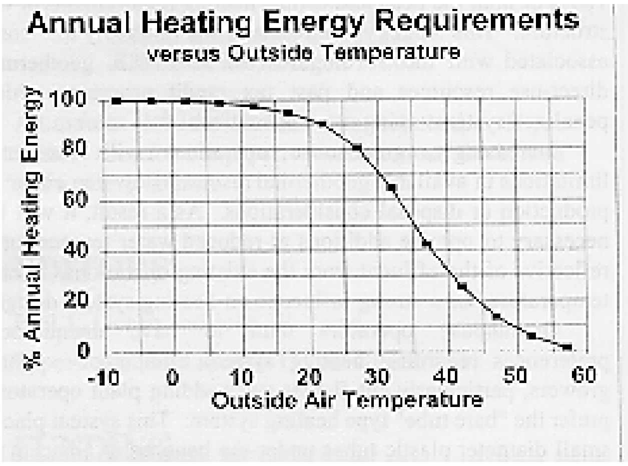

Figure 2. Cumulative heating requirement curve.

Because the base load system continues to operate in parallel with the peaking system, the percentage of annual energy captured by the base load system is greater than the value indicated in Figure 2. For example consider a base load system designed for 60% of the peak load (24°F outside temperature). Figure 2 indicates that 85% of the annual heating needs occur above this temperature. In reality, a 60% sized system could capture 97.2% of the annual requirements in this climate.

It is clear that due to the nature of temperature occurrences, the base load heating system capable of meeting only half the peak heating requirement and still meets more than 90% of the annual heating energy needs of a structure.

PEAKING EQUIPMENT CAPITAL COSTS

Two broad approaches are available for the use of conventionally-fired peak heating equipment in a hot water greenhouse heating system: individual unit heaters and central peaking boiler.

Individual unit heaters offer the advantage of zero floor space requirements (since they can be hung from the ceiling). Because each unit requires accessory equipment (flue pipe, thermostat, distribution "poly tube", fuel line, electrical connection, etc.), the cost of a given amount of heating capacity is relatively high in comparison to the boiler approach.

The central boiler approach involves the installation of a peaking boiler downstream of the geothermal heat exchanger. The boiler's function is to boost the supply water temperature to the heating equipment during the peak load period. The higher water temperature allows a down-sized tubing system to provide the required capacity to meet the space heating requirement. Because only a single piece of equipment (along with its accessory components) is required, the cost of a given heat output is much lower than for the unit heater equipment cited above. Figure 3 provides cost data for both propane and oil-fired heating equipment. Oil-fired equipment costs include a double wall, fuel storage tank.

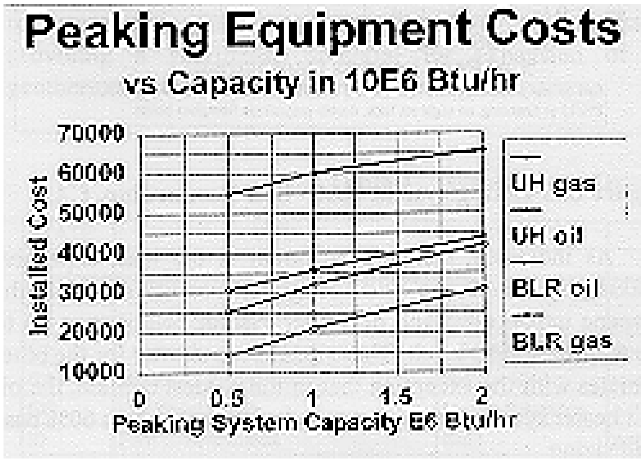

Figure 3. Peaking equipment costs.

CONTROLS AND OPERATIONAL CONSIDERATIONS

The object of the peaking equipment is to provide the capacity difference between the structure's requirement and the capacity of the base load (geothermal) system. This task must be accomplished in such a way as to produce even heat output and without compromising the performance of the base load system.

Peaking with individual unit heaters is a simple process with regard to controls. Each individual unit is equipped with a thermostat which initiates operation of the unit when additional capacity is required in the zone that it serves.

For the boiler design, the situation is somewhat more complex. This results from the boiler being incorporated into the heating loop. Because the boiler changes the temperature of the supply water, it not only influences the output of the terminal equipment but also the capacity of the geothermal heat exchanger.

As the supply water temperature rises, the output of the terminal equipment rises. At the same time, the temperature of the return water rises as well.

The rise in return temperature occurs at a rate less than the supply water increase due to the higher output of the terminal equipment (which results in an increasing system delta T). However, the rising return water temperature erodes the capacity of the geothermal heat exchanger to the extent that its capacity at the peak condition (0^oF outside) is approximately 50% or less of its capacity prior to the initiation of boiler operation.

This results in two important impacts on the economics of the boiler approach: in a given application, the boiler must be sized larger than the unit heater equipment, and fuel use for the same peaking load is higher for the boiler approach.

Figures 4 and 5 show the annual heating energy displaced by base load systems sized for 50 - 90% of the peak load at four different inside temperature settings (day/night) for the Klamath Falls, OR climate. Figure 4 is based upon unit heater systems and Figure 5, the boiler design.

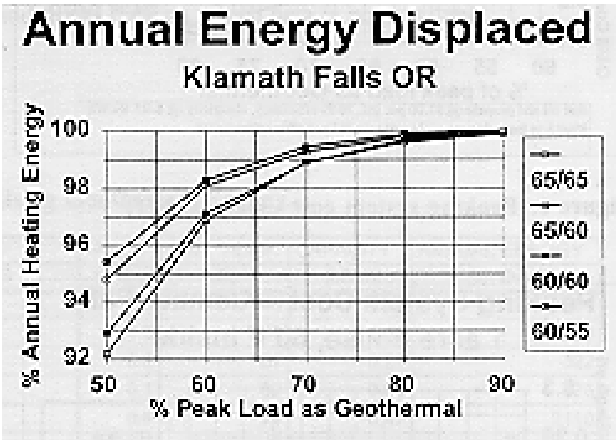

Figure 4. Annual energy displaced - unit heater system.

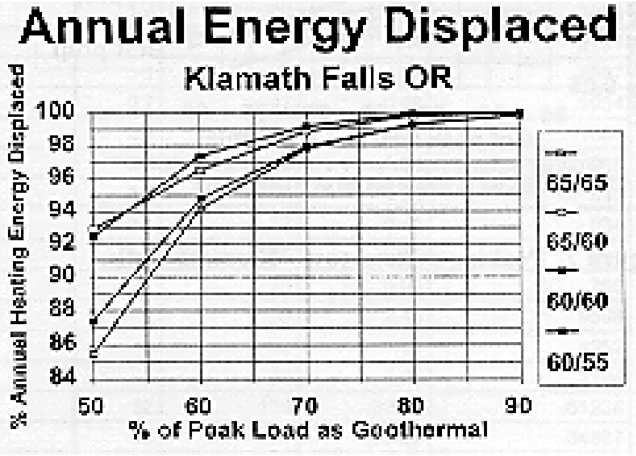

Figure 5. Annual energy displaced - boiler design.

CONCLUSIONS

The report which is summarized in this article examined the economics of fossil-fuel peaking for three different climates (Helena, MT; Klamath Falls, OR and San Bernardino, CA) representing very cold, moderate and warm climates. Figures 6, 7 and 8 present the results for these climates. Costs shown are expressed in $/ft² of greenhouse floor area and include capitalization of the equipment, fuel costs and maintenance for the fossil-fuel peaking system.

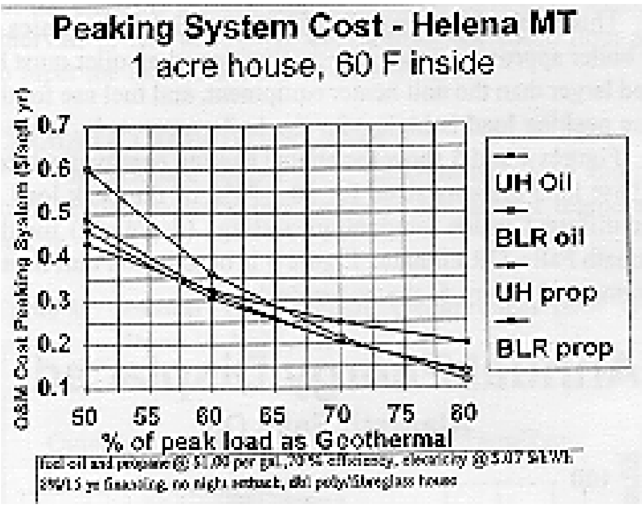

Figure 6. Peaking system cost - Helena, MT.

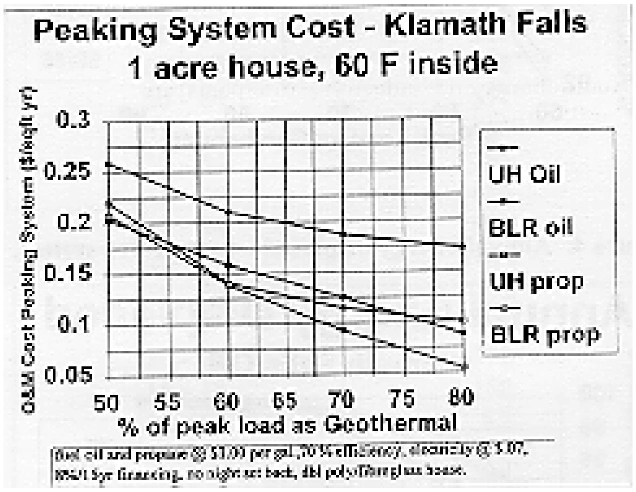

Figure 7. Peaking system cost - Klamath Falls.

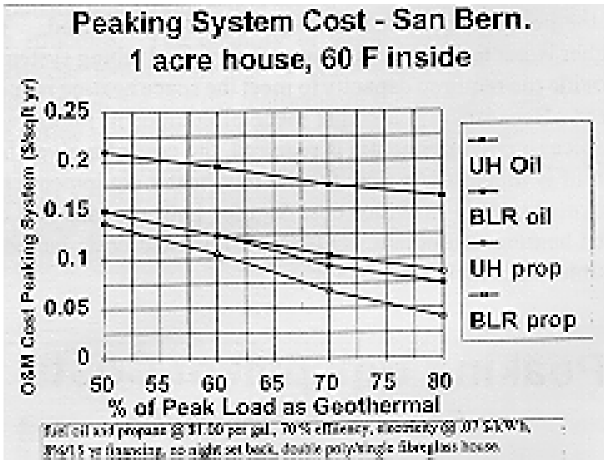

Figure 8. Peaking system cost - San Bernardino, CA.

As indicated, the propane boiler is the least expensive peaking system for a wide range of conditions, with the propane unit heaters and oil boiler system competitive up to the 65% base load level. These results are similar for the other climates with the exception that in the coldest climate, the oil unit heater system is the least cost design at less than 60% base load sizing.

It is unlikely that a base load/peak load system would be used in place of a 100% geothermal system if the decision was based solely on costs. In most, if not all, cases, the base load/peak load system will have both higher operating cost and capital cost than a geothermal system designed to meet 100% of the peak. In cases where there is limited geothermal flow available and the grower wishes to use a system which is difficult to apply at low water temperatures, the use of fossil fuel peaking permits the use of the growers preferred system for a reasonable increment in operating costs.

GEOTHERMAL GREENHOUSE DEVELOPMENT UPDATE

Paul J. Lienau
Geo-Heat Center

INTRODUCTION

Greenhouse heating is one of the popular applications of low-to moderated-temperature geothermal resources. Using geothermal energy is both an economical and efficient way to heat greenhouses. Greenhouse heating systems can be designed to utilize low-temperature (>50°C or 122°F) resources, which makes the greenhouse an attractive application. These resources are widespread throughout the western states providing a significant potential for expansion of the geothermal greenhouse industry.

This article summarizes the development of geothermal heated greenhouses, which mainly began about the mid-1970's. Based on a survey (Lienau, 1988) conducted in 1988 and updated in 1997, there are 37 operators of commercial greenhouses. Table 1 is a listing of known commercial geothermal greenhouses, we estimate that there may be an additional 25% on which data is not available.

Table 1. Greenhouse Operations Using Geothermal Energy.

STATE	SITE	LOCATION	TYPE CROPS	AREA (acre)	RES. TEMP (C)	CAPACITY (MWt)	ANNUAL ENERGY (MWh/yr)
CA	Nakashima Nurseries	Coachella	roses	2.3	48	4.39	3838
CA	Tsuji Nurseries	Susanville	cut flowers	1.5	60	1.41	2696
CA	Lake County Ag Park	Lake Co.	potted plants	0.2	67	0.21	322
CA	Big Bend Preventorium	Big Bend	vegetables	0.1	82	0.09	176
CO	Old Wright Well	Mount Princeton	potted plants	0.5	71	0.47	2110
ID	Flint Greenhouses	Buhl	potted plants	3.3	44	2.67	5831
ID	Cal Flint Floral	Buhl	potted plants	1.8	71	2.20	4805
ID	M&L Greenhouses	Buhl	potted plants	1.7	44	2.17	4747
ID	Jack Ward Greenhouses	Garden Valley	potted plants	1.6	59	2.02	4424
ID	Warm Springs Greenhouses	Banks	potted plants	1.4	82	1.76	3838
ID	Edward's Greenhouses	Boise	veg. & flowers	1.2	47	1.44	3135
ID	Crook's Greenhouse	Caksia County	cut flowers	1	90	1.17	2637
ID	Hunt Brothers Floral	Boise	potted plants	0.7	47	0.88	1934
ID	Bliss Greenhouse	Bliss	potted plants	0.4	66	0.47	1084
ID	Donlay Ranch Hot Spring	Boise County	potted plants	0.3	54	0.35	938
ID	Green Canyon Hot Springs	Newdale	vegetables	0.2	48	0.23	615
ID	Express Farms	Marsing	vegetables	0.1	37	0.12	234
ID	Riggins Hot Springs	Idaho County	potted plants	0.1	45	0.12	234
ID	Weiser Hot Springs	Weiser	potted plants	0.1	70	0.09	205
MT	High Country Rose	Helena	roses	2	66	2.46	9698
MT	Bigfork Greenhouses	Bigfork	tomatoes	1	53	1.26	4952
MT	Hunter H. S. Greenhouse	Springdale	tomatoes	1	60	1.20	3194
NM	Burgett Wholesale	Animas	cut roses	32	118	32.82	61236
NM	Masson Radium Spgs. Farm	Radium Springs	cut flowers	13	71	13.27	34867
NM	SWTDI (NMSU)	Las Cruces	variety	0.3	64	0.15	527
NM	J.&K. Growers, Inc.	Las Cruces	mixed	3	64	3.08	8087
OR	The Greenhouse	Lakeview	veg. & potted	1.2	104	1.38	3633
OR	Liskey Greenhouses	Klamath County	potted plants	1.5	93	1.73	4541
OR	Cove Hot Spring	Union County	tree seedlings	0.2	42	0.21	410
OR	Jackson Greenhouses	Ashland	potted plants	0.1	44	0.09	146
SD	Lake Wagner Greenhouse	Philip	veg. & flowers	1	68	1.14	2989
UT	Utah Natural Growers	Newcastle	vegetables	2.5	95	2.87	6036
UT	Milgro Nursery, Inc.	Newcastle	potted plants	13.5	89	11.02	24114
UT	Milgro No. 2	Newcastle	potted plants	2	95	2.29	6006
UT	Utah Roses	Bluffdale	roses	3	88	3.05	6680
UT	Christianson Bros.	Newcastle	vegetables	2.8	95	3.52	8790
WY	Countryman Well	Near Lander	potted plants	0.2	37	0.23	615
Total				98.8		103.98	230325

GROWTH AND POTENTIAL

Between the early 1970s and through the 1980s, geothermal greenhouse sites and energy use approximately doubled every five years. Although not many of these were direct recipients of federal assistance, almost all indirectly benefitted through location and confirmation of resources by programs such as the recently completed "Low-Temperature Resource Assessment Program" (Lienau, 1996) and technical assistance programs. As fuel prices leveled, the growth slowed to only a 6% annual increase between 1985 and 1990. Since 1990, an annual increase of about 10% was due mainly to several new and expanding large projects in Utah and New Mexico.

DEVELOPMENTS

Brief descriptions are given of the leading geothermal greenhouse operations listed in Table 1.

California

In California, there are four known geothermal greenhouse operations. Nakashima Nursery is located on a 16 ha (40 acre) site in the Imperial Valley, just north of the Salton Sea. A 305 m (1,000 ft) artesian well supplies 1514 L/min (400 gpm) of 48°C (118°F) geothermal fluid to a 21-unit, 9290 m^2 (100,000 ft^2) greenhouse, which supplies cut flowers to the Los Angeles market. Tsuji Nursery, located in Susanville, produces carnations and roses for the cut flower market. At Big Bend a small greenhouse is used to raise vegetables and is heated by a natural spring also used to supply mineral tubs and pools. Lake County Ag Park was developed by the county and the initial greenhouse 650 m^2 (7,000 ft^2) was constructed by Mendocino Community College as a teaching facility. The county hopes to encourage commercial growers to locate in the park, selling them energy and leasing space.

Idaho

In Idaho, there are 14 known geothermal greenhouse operations. Three separate greenhouse facilities are located near Buhl on the Snake River in southern Idaho. M&L Greenhouses ships to local nurseries and florists over 130 varieties of bedding and potted plants. Two wells supply 44°C (112°F) water to 6968 m^2> (75,000 ft^2) of space heated by a forced air system. Cal Flint Greenhouses raise potted blooming plants such as poinsettia, lilies, and chrysanthemums. This greenhouse complex also uses a forced air system to heat 7072 m^2 (76,125 ft^2) with 44°C (112°F) water. Flint Greenhouses use 44°C (112°F) water to heat 8634 m^2 (93,000 ft^2), with a forced air system, but the air is blown through polyethylene tubes under the growing tables. Potted blooming plants, including 29 varieties of chrysanthemums, are raised (Street, 1985).

At Garden Valley, a thermal spring, one mile from the greenhouses, are used to heat 6503 m^2 (70,000 ft^2) with PVC pipes buried in the ground and at Banks, 5597 m^2 (60,250 ft^2) are also heated from hot springs. After the water is used in the greenhouse, it heats two homes. Edward's greenhouses are the oldest commercial greenhouses in the state to heat with geothermal, approximately 1858 m^2 (20,000 ft^2) are under glass and 2787 m^2 (30,000 ft^2) use polyethylene covering (Street, 1985).

Montana

High Country Roses in Helena grows 40 to 50 thousand rose bushes in 0.8 ha (2.0 acres) of greenhouses. The greenhouse is maintained at 22°C (72°F) with 89 km (55 miles) of small diameter tubing supplying geothermal heat from a 66°C (151°F) thermal spring. Montana Rose & Floral (1.2 acres) near Ennis, recently closed down their operation.

Hunter's Hot Springs greenhouse near Springdale grows tomatoes for local markets. The hot springs has a total flow of 5000 L/min (1320 gpm) at 60°C (140°F). Bigfork Greenhouses, near Flathead Lake grow tomatoes in a one-acre greenhouse utilizing a 53°C (128°F) hot spring that produces 4542 L/min (1200 gpm). They are expanding the operation by adding two greenhouses per year.

New Mexico

The largest single greenhouse operation in the U.S. is at Animas, Burgett Wholesale, in southwestern New Mexico. The 13 ha (32 acres) is used for growing cut roses. Animas is near the Lightning Dock KGRA, with a resource temperature of up to 118°C (245°F), and is located at 1402 m (4,600 ft) elevation. The Beall and McCant operations, in the area, have converted to aquaculture.

The Southwest Technology Development Institute (SWTDI), at New Mexico State University, Las Cruces, operates a 1115 m^2 (12,000 ft^2) greenhouse incubator facility. This facility has been under continuous lease to commercial growers since 1986. The geothermal greenhouse research and incubator facility features innovative heating and cooling systems, fully computerized environmental controls, and state-of-the-art film cover materials. The geothermal resource temperature is 64°C (148°F) and is supplied from a 305 m (1,000 ft) well adjacent to the facility (Whittier, 1990). Technical assistance related to geothermal energy use in greenhouses is available to lessees and to commercial greenhouse operators statewide through the SWTDI staff.

Oregon

In Oregon four greenhouse operators use geothermal energy. The Greenhouse, located at Lakeview, grows vegetables and potted plants in a 0.5 ha (1.2 acre) facility. Fan coils, finned tube radiators, soil warming pipes and a snow melt system are used at the site which is supplied by a 1658 m (5440 ft) oil & gas exploratory well that produces 116°C (240°F) geothermal fluid. In Klamath County, Liskey Greenhouses grow hanging and potted plants for the local market. Thirty-two raceways use geothermal effluent from the greenhouse for raising tropical fish.

South Dakota

An artesian well, about 2.4 km (1.5 mi) north of Philip at Lake Wagner is used to provide space heating to a 0.4 ha (1.0 acre) greenhouse. The well, 68ºC (154ºF), has a shut-in pressure of about 6.9 bar (100 psi) and is also used as the domestic water supply for Philip.

Utah

At Newcastle in southwestern Utah, there are three greenhouse operators with a total of 8.6 ha (21.3 acres) of greenhouses. In July 1993, Milgro Nurseries, Inc. began construction of a 1.9 ha (4.6 acre) new facility to grow poinsettias, potted chrysanthemums, Easter lilies and geraniums. Today, the facility has expanded to 5.5 ha (13.5 acres) and utilizes about 290 km (180 miles) of bare half inch tubing for the heating system. The geothermal well produces about 6057 L/min (1600 gpm) of 89ºC (192ºF) water delivered to two plate heat exchangers. A second well was drilled this past year. The geothermal fluid is disposed of by means of an injection well, that has to be back-flowed once a week because of sediments in the well. Milgro also purchased about 0.8 ha (2 acres) of previously existing greenhouse near the new facility. Utah Natural Growers 1.0 ha (2.5 acres) and Christianson Brothers 1.1 ha (2.8 acres) grow vegetables in the same area.

Utah Roses, at Bluffdale, utilizes a 88ºC (190ºF) geothermal well to heat three acres of greenhouses with disposal to an injection well. This project was a USDOE PON project of the early 1980s.

CONCLUSIONS

The utilization of geothermal energy for greenhouses is attractive because of the significant heat requirements for these facilities and thus, a large operating cost savings in conventional fuel. The growth rate of the geothermal greenhouse industry has increased in the 1990s due to increases in fuel costs, especially propane, and in some cases high land costs and development regulations where their previous facilities were located. Competition with foreign flower growers is often cited as an impediment to new developments in the U.S. The potential of new greenhouse developments in the western states is very large. A recent resource assessment (Lienau, 1996) for 10 states identified 1,900 thermal wells and springs with temperatures greater than or equal to 50ºC (122ºF), 1,469 were located within 8 km (5 mi) of a community.

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GEOTHERMAL CARBON DIOXIDE FOR USE IN GREENHOUSES

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2. University of Stuttgart, Germany and Geothermal Institute

INTRODUCTION

Geothermal fluids often contain carbon dioxide, which is a very effective growth stimulant for plants in greenhouses. Studies have shown that as CO_2 concentration is increased from a normal level of 300 ppm (mmol/kmol) to levels of approximately 1000 ppm crop yields may increase by up to 15% (Ullmann's Encyclopedia of Industrial Chemistry, 1989). It is suggested that geothermal greenhouse heating offers a further opportunity for utilization of the carbon dioxide present in the fluid. The main difficulty is that plants react adversely to hydrogen sulphide which is invariably mixed, at some concentration, with the CO_2 from geothermal fluids. Even very low H_2S concentrations of 0.03 mg/kg can have negative effects on the growth of plants (National Research Council, 1979). Therefore, an appropriate purification process for the CO_2 must be used to avoid elevated H_2S levels in the greenhouses. The use of adsorption and absorption processes is proposed.

Two purification processes have been modelled using the ASPEN PLUS software package, using the Geothermal Greenhouses Ltd. operation in Kawerau New Zealand as an example. A greenhouse area of 8000 m^2, which would create a demand for approximately 20 kg CO_2 per hour, was chosen based on a proposed expansion at Kawerau. The Kawerau operation currently takes geothermal steam (and gas) from a high temperature 2-phase well to heat an area of 1650 m^2. Bottled carbon dioxide is utilized at a rate of about 50 kg per day, to provide CO_2 levels of 800 mg/kg when the greenhouse is closed and 300 to 350 mg/kg whilst venting. In England and the Netherlands, CO_2 levels of 1000 mg/kg are often used (Ullmann's Encyclopedia of Industrial Chemistry, 1989) and similar concentrations are desired at Kawerau, but current costs of 0.60 NZ$/kg for bottled CO_2 are too high (Foster, 1995).

H_2S LEVELS

Plants are very sensitive to elevated H_2S levels in the air. Small concentrations of 0.03 mg/kg (0.04 microg/liter) result in damage to some plants while other plant species (e.g., lettuce and sugar beets) show growth stimulation. However, all plants show deleterious effects at higher H_2S concentrations of 0.3 mg/kg (0.4 microg/liter) (National Research Council, 1979). In this study a hydrogen sulfide concentration of 0.03 mg/kg is considered acceptable if 1000 mg/kg CO_2 is added to the greenhouse atmosphere. The required CO_2 purity is, therefore, 99.997%. An H_2S content of 30 mg/kg or 40 ppm (mmol/kmol) in the CO_2, or less, has to be achieved by the purification process.

Because individual plant species respond differently, higher H_2S concentrations might be tolerable. In many geothermal areas the characteristic "rotten-egg" odor of H_2S can be detected, indicating concentrations of 0.01 to 0.2 mg/kg H_2S; higher than the concentrations where negative effects on plant growth have been observed. It is likely, therefore, that many crops currently grown in geothermal greenhouses are H_2S tolerant species, requiring less intensive CO_2 purification. The effects of hydrogen sulfide on greenhouse staff are less problematic; since, the concentrations are well below those set for US industry at 15 mg/m^3 (10 mg/kg) for an 8-hr workday and a 40-hr work week.

Non-condensable gas is typically present at 1 to 10 wt% in geothermal steam. Carbon dioxide is usually the main component, with hydrogen sulfide the next most important (approximately 1 to 5% of the CO_2 concentration). Minor components are nitrogen, ammonia, hydrogen, methane, and other gases. In this work, a geothermal steam composition of 98.6 mol% H_2O, 1.4 mol% CO_2 and 0.03 mol% H_2S was assumed. All other components were neglected. The values are typical for the main steam pipeline at Kawerau (Geothermal & Nuclear Sciences Ltd., 1992). The steam condition was assumed to be 12 bar (absolute) at saturation conditions.

ABSORPTION

An absorption process is suggested for recovery of CO_2, which will first require cooling of the fluid stream to condense the steam fraction. This heat could be used to warm the greenhouse. The water fraction remaining in the gases depends on the condensation pressure and temperature. Normally a low water fraction is an advantage, but the required heat transfer area increases enormously as full condensation is approached. Sizing of the heat rejection system is, therefore, critical to the success of such an operation and sensitivity to this parameter has been investigated.

Absorption is the uptake of gases by a liquid solvent. The equilibrium solubility determines the distribution of the absorbed material between the liquid and vapor phases. Depending on its volatility, the solvent can also appear in the vapor phase. During physical absorption, the absorbed molecules become polarized but remain chemically unchanged. In chemical absorption, a chemical conversion takes place. Equilibrium between the phases is determined by general thermodynamic principles and was predicted using theoretical models available within the ASPEN PLUS package. As yet, no comparison with between predicted and experimental data has been made; but, experience with other simulations indicates that accuracy greater than 80% can be expected for the equilibrium prediction.

In an absorber, gas and liquid are brought in contact counter currently. The solvent removes one or more components from the gas mixture, more or less selectively. Normally, the laden solvent is withdrawn from the bottom of the absorber column and freed of the absorbed gas in a recycling system. It is then returned to the absorber. In most cases reversible processes are used and the dissolved components are released chemically unchanged.

PHYSICAL AND CHEMICAL ABSORPTION

The pressure dependence of physical and chemical absorption is significantly different. Typical equilibrium lines are shown in Figure 1, where loading capacity is presented as a function of the dissolved component. Physical absorption processes generally follow Henry's Law, so the liquid mol fraction of a component depends strongly on partial pressure (line b, Fig. 1). In chemical absorption, however, the equilibrium line is sharply bowed. After chemical saturation of the solvent, only weak physical absorption takes place. At low partial pressure the absorption capacity of the chemical solvent is much higher than that of the physical solvent; whereas, at higher partial pressure the opposite applies.

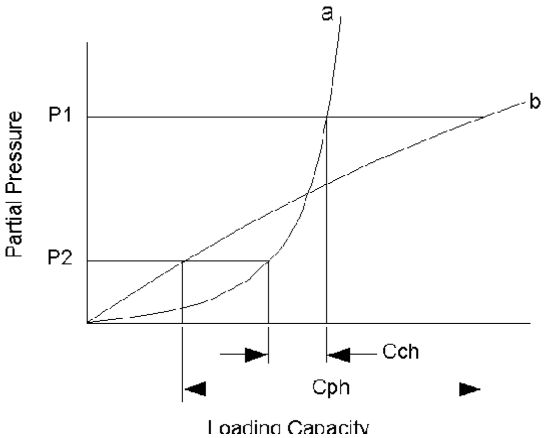

Figure 1. Equilibrium lines for chemical and physical absorption (Ullmann's Encyclopedia of Industrial Chemistry, 1989).

The strong pressure dependence of physical solubility can be utilized for solvent regeneration; since, pressure reduction releases most of the absorbed gas. However, if the dissolved components are chemically bound, less gas is released (Δcch < Δcph) and reboiling is almost always needed for regeneration of a chemical absorbent. Heat required for reboiling could be provided by hot geothermal fluids in this case.

In a physical absorption process, the solvent circulation rate is nearly proportional to the quantity of the gas to be cleaned. In contrast, the solvent circulation rate for a chemical process is proportional to the quantity of gas to be removed. This means chemical absorption processes are most economical with low levels of impurity; whilst, physical processes are more suitable for bulk removal of impurities. Examples of both processes have been investigated. The main difficulty is to find an appropriate absorbent that selectively absorbs H_2S.

THE PHYSICAL ABSORPTION PROCESS

Water was selected as the absorbent for the physical process, since it is cheap and freely available and H_2S and CO_2 have different solubilities in water. Unfortunately, although H_2S is considerably more soluble than CO_2, both gases are only slightly soluble in water. Relatively high circulation rates are, therefore, required. Solubility decreases with increasing temperature, so absorption should take place at a low temperature. Despite the low solubility and high flow rates in this small scale application, a relatively simple process is required, and the use of water is considered appropriate.

The flow sheet of an absorption process with water is shown in Figure 2. After condensation and cooling to 120°C, the steam/gas fraction is separated in a flash tank at 10 bar and fed into the base of the absorber column; while, the separated water is removed for further use or disposal. Cool water fed into the top of the column absorbs the H_2S and some CO_2 as it passes downward, and purified CO_2 flows from the top of the absorber.

The gas laden absorbent is then flashed at 3 bar, releasing mainly CO_2, which is recycled into the absorber column by the compressor. Without recycling, much of the CO_2 would be lost with the H_2S. Flash regeneration alone is not sufficient to achieve the required CO_2 purity so a steam heated regeneration column is used as a final stage. At 133°C, almost all the absorbed CO_2 and H_2S are released in this column and a water purity of 0.5 ppb H_2S is achieved. Heat needed for regeneration could be supplied using the heat exchanger in which the inlet steam is condensed; however, low cost steam is available and direct injection of steam seems appropriate. Finally, the water stream is recycled to the absorber after rejecting heat to the greenhouse.

Unfortunately, the process as presented cannot reduce the H_2S to 40 ppm, due to a limitation on the purity of the regenerated water. This process can remove H_2S from the CO_2 down to 400 ppm so residual H_2S must then be removed using an appropriate adsorption process. It is possible to achieve a CO_2 purity of 99.997 % (40 ppm H_2S) with a more complex absorption process using water, but the high water flow rates and heat loads are unlikely to be economical.

Production of approximately 20 kg/hr CO_2 requires an inlet steam flow of 1200 kg/hr (~40 kg/hr CO_2). After initial separation 37 kg/hr CO_2 is passed to the absorber, where 22 kg of CO_2 are recovered, at a water flow rate of 4000 kg/hr. About 0.5 kg/hr of H_2S is removed, reducing H_2S content from 1.4% to 400 ppm. Unrecovered CO_2 is removed with the H_2S. The predicted power requirement is 4.3 kW, made up of water pump power (3.3 kW - efficiency 30%) and gas recycle compressor power (1.0 kW - efficiency 72%). The CO_2 recovery rate increases if the flash tank pressure is reduced (or temperature increased); but, water circulation rates and compressor power increase significantly. Regeneration requires 800 kg/hr steam to heat the circulating water to 133°C so approximately 1250 kW_{th} of heat is removed from the steam in total. It is anticipated that a reasonable proportion of this heat can be used in the greenhouse.

One major constraint is the need to condense inlet steam in the presence of very high levels of non-condensable gases. This would require a large heat exchanger area and careful attention to heat exchanger design. A range of higher condensing temperatures have, therefore, been considered; with

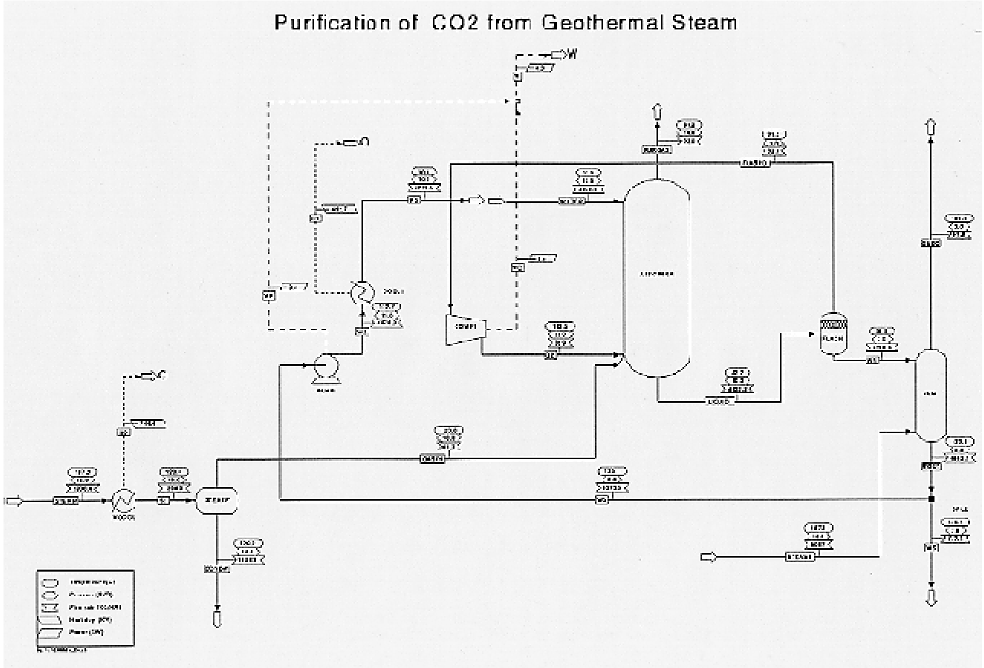

Figure 2. Flow sheet arrangement for absorption process with water.

absorber inlet temperature varied between 24 and 50°C. The influence on the required water flow rate, electrical power requirement, flow rate of regeneration steam, and water cooling load can be seen in Figure 3. Production of purified CO_2 increases by about 10% as the temperature increases from 24 to 50°C.

Gas solubility decreases at higher temperatures; so, the absorber flow rate and regenerator steam flow both increase with temperature. Pump power increases correspondingly, although higher pump efficiency is predicted for larger pumps; hence, the change in power curve slope at 32°C. The cooling load also increases; but, due to an increased temperature difference, the heat transfer area is reduced. Purified CO_2 production increases slightly at higher temperatures; since, less CO_2 is absorbed with the H_2S.

TEMPERATURE OF GAS INLET STREAM

The heat exchanger area required for condensing the inlet steam depends on the outlet temperature. Lower temperatures require disproportionately larger areas; as, the non-condensable gas partial pressure rises in the condenser. Sensitivity to this parameter was tested by varying temperature in cooler from 70 to 170°C.

As the water saturation temperature is approached (10 bar - 180°C), the steam fraction increases significantly, heating the bottom stage of the absorber column (Fig. 4). The increased temperature reduces CO_2 absorption and production of purified gas increases. More gas is recycled, increasing compressor power slightly. The cooling load reduces and the required heat exchanger area is greatly decreased due to the a higher temperature difference and higher water fraction in the non-condensable gases. Because the electricity costs increase significantly for a small increase in purified gas flow, it is advisable to reduce the gas inlet temperature as far as possible within economic limits imposed by the cooling load.

REQUIRED CARBON DIOXIDE PURITY

The purity achieved in the absorption process determines the costs for the second purification stage, which is an adsorption process. Water flow rates decrease significantly if higher H_2S levels in the purified CO_2 are specified. Compressor and pump power also reduce (Fig. 5). For example, the power requirement decreases from 4.3 to 2.9 kW if a CO_2 purity of 99.90% instead of 99.96% is acceptable. Furthermore, the flow rate of purified CO_2 increases if higher H_2S levels are specified; since, less CO_2 is absorbed with the H_2S. Increasing the H_2S level from 200 to 1500 ppm provides over 50% more CO_2. Obviously it is important to carefully evaluate the required CO_2 purity for the first stage.

SIZE OF ABSORBER AND REGENERATION COLUMN

The vessel sizing option of the ASPEN PLUS program has been used to estimate vessel size. For the base process described, an absorber column size of 1.5 m height and 0.27 m diameter with a random packing of 1-inch plastic pall rings would be sufficient. Pressure drop in the column is negligible due to the very low gas flow rate. The regeneration column requires a larger diameter (0.47m), due to the higher flow rate, once again assuming random packing with 1-inch plastic pall rings. A packing height of 1 to 1.5 m is expected to be sufficient. These values show that the vessels are relatively small and pipes could probably be used to construct the columns, keeping costs down.

CHEMICAL ABSORPTION PROCESS USING MDEA

Chemical absorption of unwanted hydrogen sulfide was also investigated. Several solvents are available, and aqueous amine solutions have been used extensively in the oil and gas industry (Ullmann's Encyclopedia of Industrial Chemistry, 1989). In this horticultural application selective removal of H_2S is important. Good selectivity is shown by tertiary

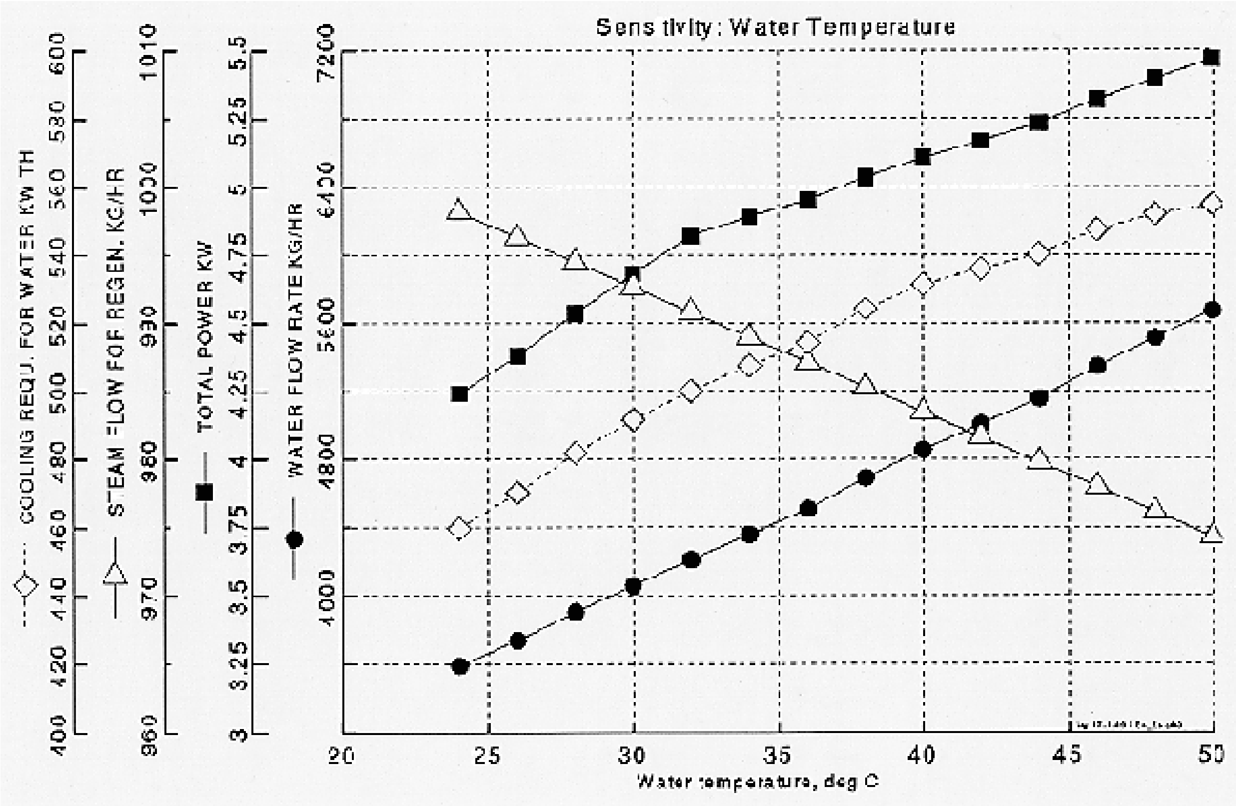

Figure 3. Influence of water temperature on mass flow rates, cooling load and power requirements.

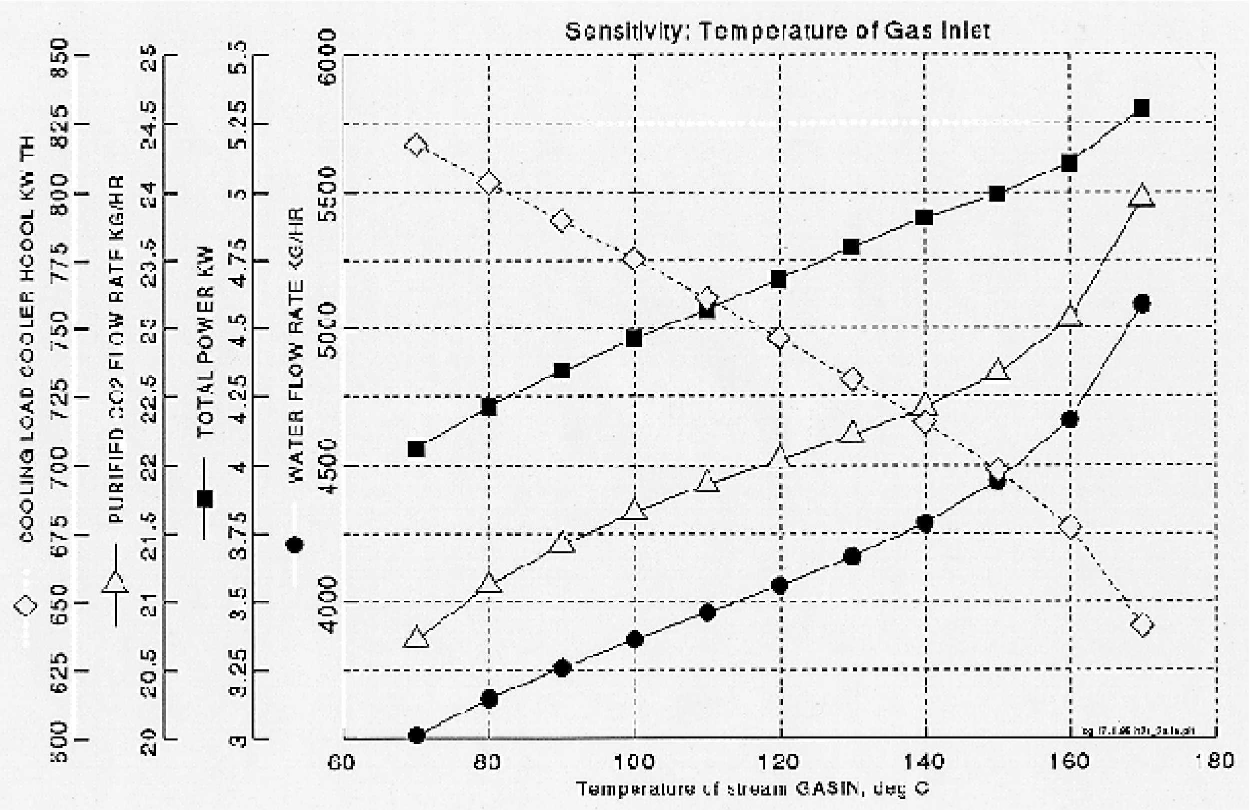

Figure 4. Influences of gas inlet temperature on water flow rate, power requirements, condenser cooling load, and purified CO_2 flow rate.

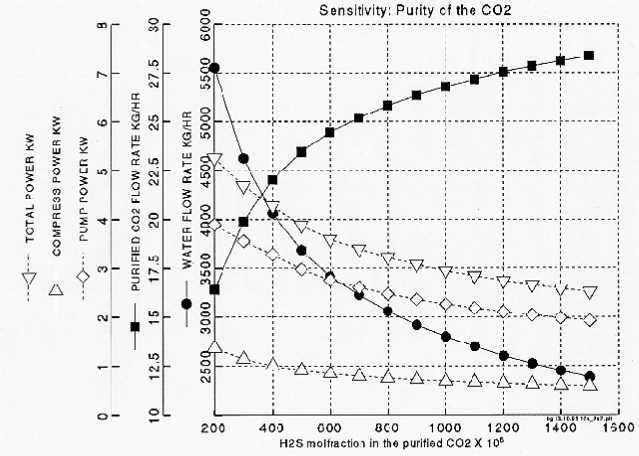

Figure 5. Influence of the specified H_2S fraction in the purified CO_2 on the absorption process.

alkanol-amines (Ullmann's Encyclopedia of Industrial Chemistry, 1989; Savage, et al., 1986), of which the most commonly used is an aqueous solution of n-methyldiethanolamine (MDEA). Chemical equilibria for the MDEA solvent were calculated using the ASPEN PLUS built-in data bank. Typically MDEA concentrations of 2.5 to 4.5 mol per liter are used for acid gas absorption (Kohl, et al., 1995). For this simulation a 4 M aqueous MDEA solution (27% by weight) has been chosen.

An H_2S concentration of 1000 ppm in the purified CO_2 stream has been specified for this process. Residual H_2S is then removed in an appropriate adsorption process, as for the physical absorption process. Although higher purities can be achieved, a very high heat duty is required for solvent regen-eration. Furthermore, as CO_2 is absorbed with the H_2S it becomes difficult to selectively recover CO_2.

The flow sheet for the simulated absorption process with MDEA is shown in Figure 6. This process is similar to that used for physical absorption with water with the following modifications:

- Inlet steam (and gas) is condensed at 2.5 bar and 100°C, as a lower absorber pressure is acceptable;
- Absorber column temperatures are higher and the MDEA solution enters the column at 70°C;
- Purified CO_2 is cooled to 60°C in a gas cooler and condensed water is separated out. This step was included for satisfactory simulation of the H_2S fraction in the purified CO_2, as the high water fraction in the absorber gas outlet results in a low H_2S mol fraction. In practice, this step may not be necessary;
- The flash tank is slightly heated to improve CO_2 recycling to the absorber; as, pressure reduction alone is not sufficient;
- Regeneration of the chemical solvent requires the use of a true reboiling process; where, the solvent is evaporated and stripped with its own vapor, rather than heating directly with steam containing H_2S, and
- Water lost from the solvent in the gas outlet stream is replaced by make-up water at a temperature of 30°C before recycling to the absorber.

Compared to the absorption process with water the main differences with MDEA are:

- Absorbent flow rate is substantially lower with 785 kg/hr required, compared to more than 4000 kg/hr;
- The pump and compressor are much smaller due to the lower flow rate and the reduced pressure differences. The power requirement is 0.4 kW, about 10% that of the water system, and capital cost will be lower;
- Regenerator heat loads are relatively high (780 kW) at the required purity (~50 ppm H_2S). This heat load could be met by condensing about 1200 kg/hr steam, so initial condensation of the inlet steam/gas mixture could supply the regenerator. Ultimately, most of this heat is rejected from the regeneration column at lower temperatures (~100°C) and much of it could be used in the greenhouse;
- The circulating solvent requires just 26 kW of cooling to achieve the required temperature of 70°C;
- The temperature of the purified gas is relatively high at 87°C, and
- Approximately 11 g/hr MDEA are lost in the waste gas outlet stream. Cooling the outlet stream and recycling the condensate can reduce this loss significantly. Only trace amounts of MDEA are expected in the purified CO_2. Condensed water from the purified CO_2 stream should be recycled as it contains 120 ppm MDEA.

The MDEA absorption process has the advantage of lower circulation rates, lower electricity demand, lower pressures, and higher cooling temperatures. The disadvantages compared with the water absorption system are a higher heat requirement, lower CO_2 purity and minor losses of MDEA.

ADSORPTION PROCESS FOR FURTHER PURIFICATION OF THE CO_2

Purities achieved with either of the absorption processes discussed are not sufficient for direct use of the CO_2 in greenhouses. Further purification is, therefore, required to reduce H_2S concentration from 400 or 1000 ppm to 40 ppm or less. Approximately 5 to 20 g/hr of H_2S has to be removed in this final step, so a simple solution is an adsorption process without adsorbent regeneration. The advantages of an adsorption process are high selectivity and a loading capacity that is almost independent of partial pressure.

Selective adsorption of H_2S can be achieved using activated carbon. The loading capacity of 50-min activated coconut-shell charcoal for H_2S is approximately 10 to 25 % by weight (i.e., 1 kg of activated charcoal can adsorb 100 to 250 g of H_2S) (Kohl, et al., 1995). Other activated carbon products are expected to have similar capacities. Assuming a loading capacity of 10%, approximately 25 to 100 g/hr

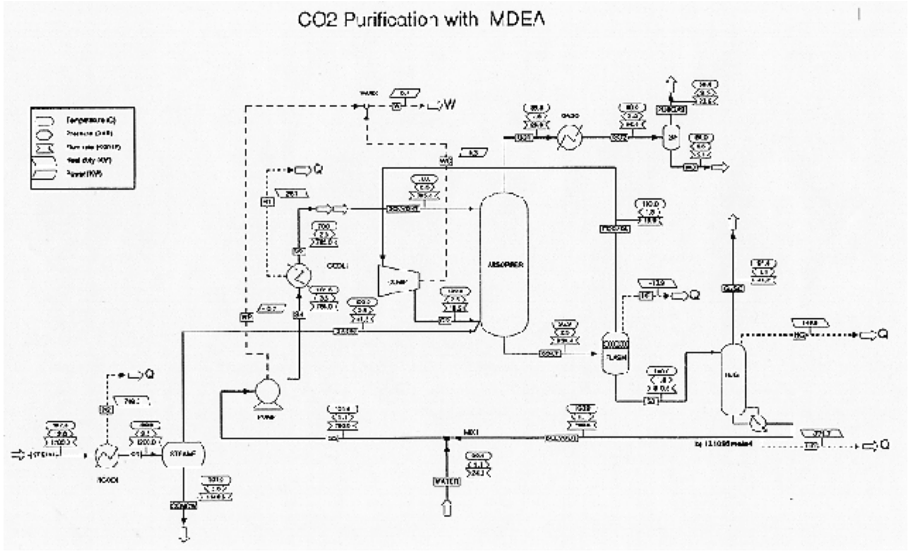

Figure 6. Flow scheme for chemical absorption with MDEA solution.

activated carbon would be required for final purification of CO_2 that had been pre-treated in one of the absorption processes. The costs of activated carbon products are 0.70 to 5.50 $US/kg (Encyclopedia of Chemical Technology, 1992). Material costs for this adsorption process are, therefore, relatively low. However, the operating cost involved in exchanging the activated carbon filters should be considered.

Assuming electricity costs of 0.07 $US/kWh and a cost of 3.5 $US/kg activated carbon, the total costs are approximately 0.40 $US/hr for the process with water and 0.35 $US/hr for the process with MDEA. The costs for both methods are similar because the achieved purity with the MDEA process is lower than that achievable with the water process, increasing the activated carbon consumption. The value of the purified gas is approximately 8.4 $US/hr or 70,000 $US/year, which is many times greater than the costs calculated above (approximately 3,500 $US/year).

The required quantity of activated carbon depends on the purity achieved by the absorption process and an economic optimum for the combination of both processes requires careful further study.

CONCLUSION

The use of geothermal carbon dioxide for growth stimulation of plants is possible, if a purification process is used to reduce the initial hydrogen sulfide content. Alone, an absorption process using water or aqueous MDEA is not feasible at the required purity. However, both processes are suitable for bulk removal of H_2S and it is possible to remove residual H_2S with an activated carbon adsorption process.

Power requirements for purification of 20 kg CO_2/hr are relatively small: 4.3 kW for physical absorption with water and 0.4 kW for chemical absorption with MDEA. Activated carbon consumption is approximately 20 to 100 g/hr. Running costs are approximately 0.40 $US/hr for the physical process with water and 0.35 $US/hr for the chemical process with MDEA. The product value is about 8.4 $US/hr; so, either of these combination processes appear economically attractive compared to current use of bottled CO_2.

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GREENHOUSE CLIMATE FACTORS

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INTRODUCTION

There are many examples of geothermally heated greenhouses throughout the world, even in warmer climates. The main reason for using geothermal heating systems is that greenhouses are one of the largest energy consumer in agriculture. This concentrated demand for energy can be satisfied, in the case of geothermal, by siting facilities near wells even though they are located far from urban areas and industrial concentrations.

The reasons for this high energy requirement are in the nature of the greenhouse construction itself:

- Greenhouses are typically constructed of light materials that have very poor insulating qualities, and
- The "internal" climate of the greenhouse are usually significantly different than the external one, especially during the colder seasons.

GREENHOUSE CLIMATE

One of the main tasks in greenhouse construction is to optimize the conditions for plant development, generally during the off-season from normal outside field production. The "internal" or greenhouse climate factors required for the optimal plant development involve photosynthesis and respiration.

Photosynthesis, or the active process, is the formation of carbon dioxide through solar radiation and can be expressed by the following simplified balance equation:

$$6CO_2 + 6H_2O + 2{,}810\ \text{kJ} = C_6H_{12}O_6 + 6O_2 \qquad (1)$$

On the contrary, respiration is expressed as:

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 2{,}810\ \text{kJ} \qquad (2)$$

These equations do not represent the real situation, which is more complicated, but can be used to define the energy aspect of greenhouse climate: the water transport, CO_2 separation and energy intake, along with the creation of chlorophyll and O_2 that result from the natural or artificial application of light.

It is not possible to understand greenhouse energy demands in order to calculate heat (or coldness) requirements, without the essential knowledge of the "greenhouse climate." This climate is composed of parameters that are variable and interdepedndent, and are influenced by external climate changes, the stage of the plant development and other factors.

In principal, four physical phenomena are responsible for the differences between greenhouse and external climatic conditions:

1. Solar radiation, in particular the short waves, penetrates the glass or plastic covering of the greenhouse practically without any loss. On reaching the soil surface, plant canopy, heating installation, etc., the radiation changes to long-wave, and can no longer pass through the covering, or with difficulty. Most of the radiation is trapped within the greenhouse space, raising the inside temperature;

2. The enclosed air within the greenhouse is stagnant: local air velocity is much smaller than it is outside and the effects of temperature transfer are entirely different;

3. The concentration of plant mass in the greenhouse space is much higher than outside. Artificial control of humidity and condensation clearly creates a different mass transfer from outside the greenhouse, and

4. The presence of heating and other installations changes some of the energy characteristics of greenhouse climate.

Taking into account the real meaning of the equation (1) and (2), and the associated physical phenomena, it is possible to simplify the definition of greenhouse climate and to state that it is a physical process of predominantly energy related character. The main processes are the water transport between the plant canopy, air and soil in the greenhouse, the chlorophyll composition and degradation under the influence of solar light, energy transfer, and CO_2 and O_2 flow.

The values of these parameters, their interdependencies and changes determine the limiting conditions and character of greenhouse climate.

LIGHT

Light is the most significant parameter for the plant development and life. All the active life process in it can be achieved only in the presence and active influence of light.

When speaking about natural light, meaning solar light, it is necessary to distinguish:

- Solar radiation with specific influence to the life processes of the plants, and
- Solar radiation with energy related influence to the plants, directly or indirectly through the influence of the environment.

By the use of different scientific methodologies and investigations of changes in photosynthetical, phototropical, photomorphogenical and other plant activities, it is found that only the part of total solar spectrum between 400 and 700 nm influences significantly plants life processes (Figure 1). That determines the quality of transparent materials for greenhouse cover– it must be maximally transparent to this part of the solar spectrum.

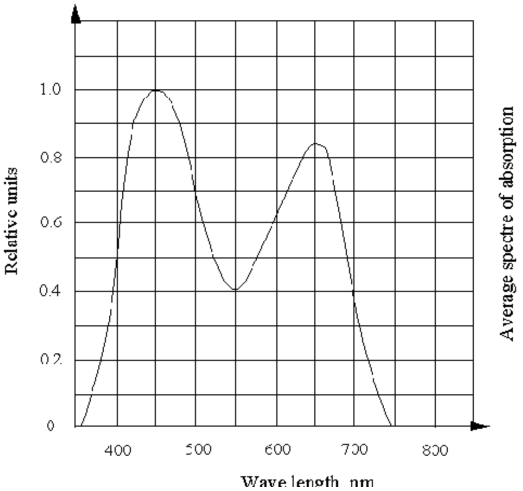

Figure 1. Average specter of absorption "in vitro" of chlorophyll pigments (Dogniaux & Nisen, 1975).

The intensity of the energy related part of the total spectrum of solar radiation (i.e., the infra-red one) offers the necessary energy to the plant (Equation 1). Depending on its intensity, life processes are more or less active (Figure 2). Up to some characteristical levels (different for different species) life processes increase their activities; but, after a point, they start to decrease. Below and above these characteristical light intensities, there is no life activity in the plant. Below, because active life processes need light to be activated. Above, because the plant is over- heated and processes of "cooling" are activated.

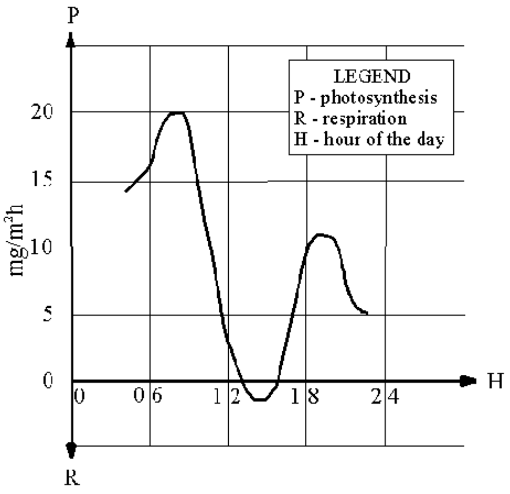

Figure 2. Changes of photosynthetical activity during the summer day (Kamenev, 1975).

To improve light conditions, artificial light is used when the natural one is not available, or shaded when the light intensity is too high.

Light intensity also affects the values of other parameters of greenhouse climate.

AIR TEMPERATURE

Air temperature influences the energy balance of the plant canopy through the convective heat transfer to the plant leaves and bodies. Depending on the character of the air movement in the greenhouse, it is more or less near the temperature of the plant itself.

The optimal level of the air temperature in the greenhouse depends on the photosynthetical activity of the plant in question, under the influence of the intensity of solar radiation on disposal (Figure 3) (i.e., for each light intensity, there is an optimal air [leaf] temperature, enabling maximum photosynthetical activity).

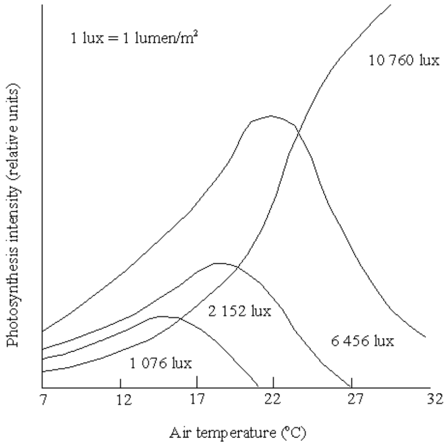

Figure 3. Photosynthesis activity vs. light and air temperature conditions (tomato culture)(Kamenev, 1975).

Due to the changeable character of greenhouse climate, it is not possible to provide the "optimal" air temperature for some plants due to interdependencies of the light intensity and other parameters of greenhouse climate.

Trials to define norms for optimal temperature values or intervals should not be understood as a tool for determination of optimal greenhouse climate (Table 1), but as a basis orientation for the choice of design values for calculation of greenhouse heat requirements and consumption.

SOIL OR PLANT BASE TEMPERATURE

Soil, or plant base temperature influences the energy balance of the plant canopy, too. The influence is by conduction heat transfer directly between the soil structure and through convection between the plant roots and water flow around them.

Through a great number of experiments and investigations, it is proven that:

- Optimal soil (or base) temperature depends on the stage of development of the plant in question (Table 2);

Table 1. USSR Norms for Optimal Values of Air Temperature and Humidity in Greenhouses for Vegetable Cultivation (Source: Kamenev, 1975)

	Inside Air Temperature (°C)							
		Development			Harvesting			
Vegetable	Germination	Day*	Day*	Night	Day	Night	Young Plants	Relative Humidity of the Air (%)
Cucumbers	17-18	22-25	27-30	17-18	25-30	18-20	13-15	85-95
Watermelon and melons	17-18	22-25	27-30	17-18	25-30	18-20	13-15	65-75
Tomatoes, apple, paprika, and beans	10-12	20-22	25-27	10-13	22-28	15-17	8-10	50-60
Lettuce, celery and garlic	8-9	17-18	20-26	8-12				70-80
Spinach and parsley	8-9	15-16	20-21	8-9				70-80
Radish and cabbage	6-7	12-13	16-18	7-8				65-75

* Inside design temperature ranges for different crops.

- Optimal soil (or base) temperature depends on the light intensity available, and
- Soil (or base) temperature influences the value of the optimal air temperature (i.e., higher soil temperature requires lower air temperature and vice versa).

Table 2. Optimal Soil Temperatures for the Tomato Culture

	Optimal Soil Temperature Intervals	
Phase of Development	Low Intensity of Light (°C)	Strong Intensity of Light (°C)
Development before flowering	13-14	17-20
Flowering	15-16	19-22
Harvesting	20-22	23-25

It is necessary to stress that moving away from the optimal values influences the development of the root system of the plant, in the production capacity and the quality of the product. Going to lower values means decreasing production and going to higher values means drying of the root system, and in that way also reducing the production capacity and quality of the products.

Thus, if knowing the nature and requirements of plants, it is possible to influence significantly the heat consumption of a greenhouse through the balance between the air and soil temperatures during the plant cultivation.

CO_2 CONCENTRATION

Normal CO_2 concentration in the atmosphere is about 0.03%. In the case of a closed room under influence of high light intensity and, therefore, high photosynthetical activity (Equation 1), it changes quickly. During a bright day, its concentration can decrease to 0.01% in only a couple of hours for a good tight greenhouse.

As the CO_2 is an active participant of the chlorophyll assimilation, it is a greenhouse parameter of crucial importance. Also through a long process of experimentation and investigation, it is proven that:

- For constant temperature conditions in a greenhouse, CO_2 concentration influences directly the intensity of photosynthetical activity, and

- Optimal concentration of CO_2 in the greenhouse depends directly on the light intensity on disposal (Figure 4).

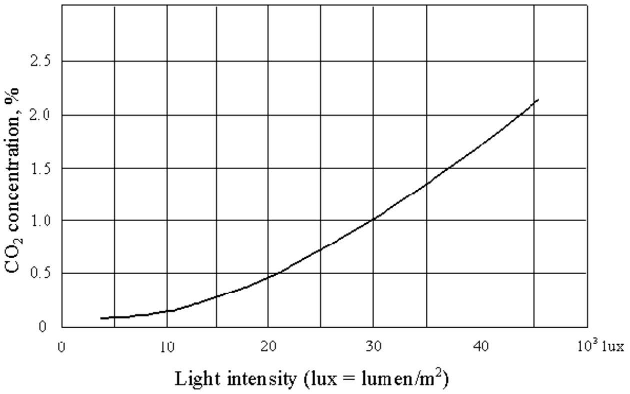

Figure 4. Optimal concentration of CO_2 in the cultivation area of a greenhouse depending on the light intensity (Denis, et al., 1978).

Through the ventilation of greenhouse closed space with 5-6 (vol/h) air exchange, it is possible to keep about a 0.02% CO_2 concentration. It is a compromise, because going to 9-10 (vol/h) exchange enables one to keep about a 0.03% concentration, but this influences significantly the heat consumption of the greenhouse. Middle- and northwest-European climatic conditions require the use of artificial measures to keep the necessary optimal CO_2 concentration; but, in the southern regions, usually controlled ventilation is sufficient.

AIR MOVEMENT IN THE GREENHOUSE

The character and velocity of the air movement in the greenhouse influences:

- The intensity of the heat transfer between the air and plant canopy, and

- The intensity of the water exchange between the air and plant canopy.

At the same time, both processes are directly connected to the energy balance of the plant canopy and, in that way, the intensity of the life processes in it.

It is found that velocities between 0.2 and 0.7 m/s provides the optimal heat exchange if the air stream is vertical (i.e., from bottom to the top of the plant). With some types of heating installations, it is easy to obtain this; but, with most of them, it creates a negative influence in the heat consumption of the greenhouse. Before making the final choice of the heating installation for a greenhouse, it is very important to investigate its positive and negative sides connected to the character of air movement in the greenhouse interior.

WATER TRANSPORT IN A GREENHOUSE

Water transport between the plant canopy and the environment is one of the most important parameters of the photosynthetical activity (Equation 1). It has been proved that it depends mainly on:

- The light intensity on disposal (Figure 5);

- Temperature of the environment (Figure 5), and

- Root characteristics of the plant in question in combination with the "ability" of the cultivation base to offer the necessary water quantity, but also on the air humidity of the plant environment.

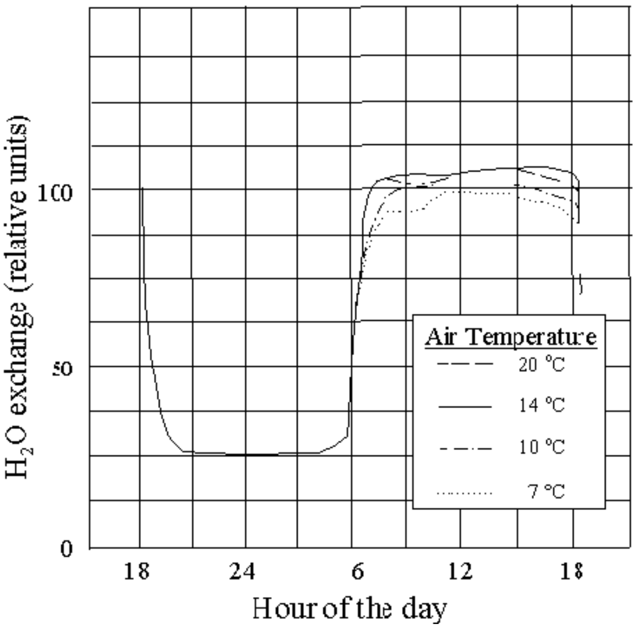

Figure 5. H_2O exchange of tomato plants before flowering.

The last parameters are of particular interest, since they influence the greenhouse climate characteristics. There is a direct relationship between the air humidity and soil moisture (or artificial cultivation base characteristics) in a greenhouse.

Air humidity directly influences transpiration of the plant leaves. Optimal intervals are rather small and difficult to be achieve in a closed room, filled with crops of high transpiration (Table 1). Lower humidity means drying of the plant and reduced production. Higher humidity produces more leaves, lower quality of fruits and sensitive to a number of plant diseases.

The intensity of the water transport of the plants depends directly on the light intensity (Curve ETP outside (light conditions), Figure 6). It is normally smaller in greenhouses and is connected to the light transmittance of their material (Curve ETP inside (light conditions), Figure 6). Depending on the stage of the plant root development and air humidity in the closed room, real water transport is smaller even than the inside one (Curve actual ETP, Figure 6).

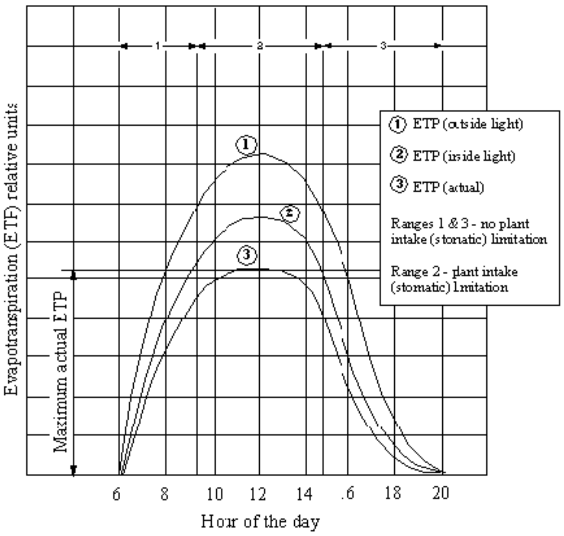

Figure 6. Potential evapo-transpiration (ETP) in a greenhouse (Dogniaux, Nisen, 1975).

HEATING INSTALLATION

Heating installation is an active parameter of the greenhouse climate because it influences:

- The character and velocity of the internal air movement (Figure 7);
- The radiation intercepted by crops by exposure pipe view factor to the heating elements, and in that way, tempera-ture distribution of the plant leaves (Figure 8), and
- Vertical and horizontal distribution of internal air temperatures (Figure 9), and the effect on the plant leaves temperatures.

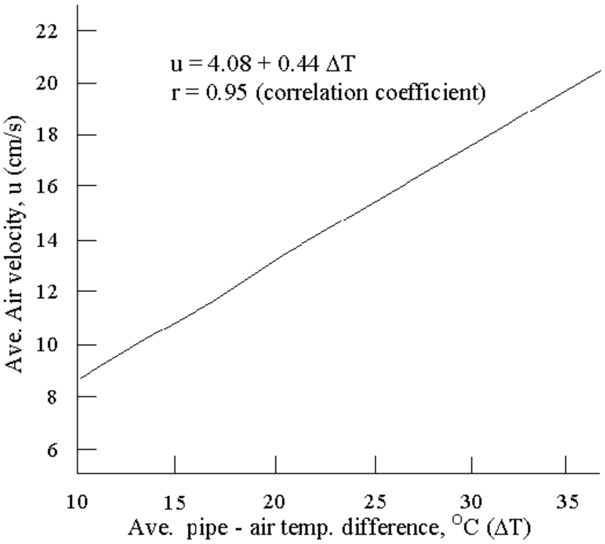

Figure 7. Internal air velocity as a function of temperature difference between the pipe surface and the air (Slanghellni, 1983).

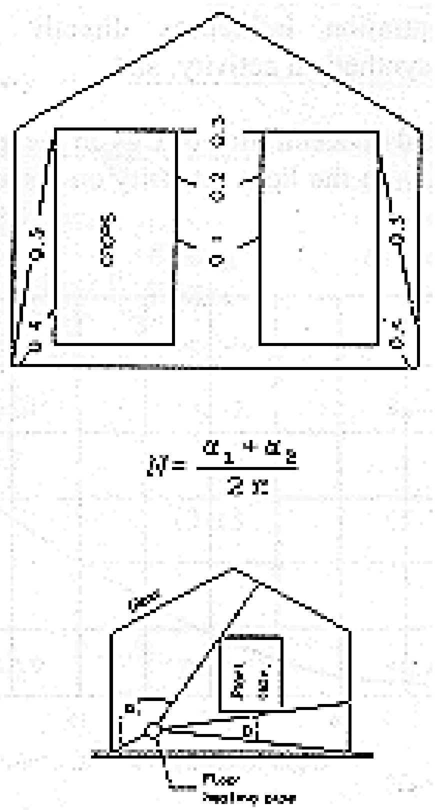

Figure 8. Effect of radiation interception by crops on the pipe view factor of heating pipes (Okada and Takakura, 1978).

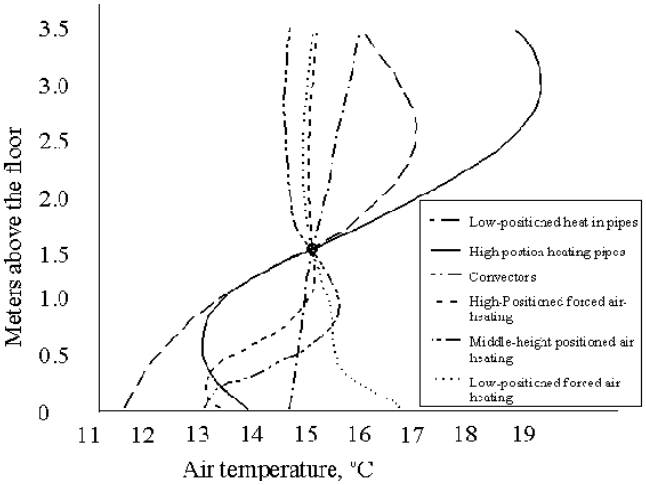

Figure 9. Vertical air temperature profiles in a greenhouse heated by different types of heating installations.

The type and location of the heating installations influences the temperature distribution and internal air movements (i.e., energy distribution and water transport of the plant canopy), which ultimately impacts the intensity and distribution of the photosynthesis.

ENVIRONMENT

The environment of a greenhouse includes the outside air, atmosphere and soil around it. Since the greenhouse climate is enclosed by transparent partitions, it is actively influenced by the outside environment.

A transparent wall has no (or very small) thermal inertia and each change of outside temperature conditions directly influences the ones in the greenhouse. The wall is transparent to a significant part of the solar radiation spectrum, and each change of it means a change of the inside climate conditions. Numerous leaks and the ventilation openings allow the outside air to enter in the greenhouse. Each change in velocity and direction changes directly the temperature distribution in the greenhouse. During the night and cloudy days, the atmosphere radiates "coldness" to the greenhouse interior and changes the temperature distribution of the plant canopy. Exposed parts are always colder than non-exposed ones (Figure 8).

OPTIMAL GREENHOUSE CLIMATE

When taking into account Equation 1 and the known dependence of the plant life processes on the light composition and intensity, the "greenhouse" climate is a rather simple physical quantity:

$$GK = F(I, T_a>, CO_2, H_2O) \qquad (3)$$

where:

I = Light intensity (W/m^2, lumens)

T_a = Plant leaves temperature (K)

CO_2 = CO_2 concentration in the air around the plant canopy (%), and

H_2O = Internal air humidity and soil (plant base) humidity (i.e., moisture) (%).

Temperatures and partly the light are quantities of an energy nature and the others are not.

For each plant and its stage of development, it is possible to define the optimal values of influencing parameters, and then it is necessary to keep them constant. That should result in maximum production results and quality of the fruits and flowers. In a number of laboratories, it has been experimentally proven that this way of thinking is a correct one.

Unfortunately, it has also been proven that it is difficult to make a profit. Even distribution of light with a defined spectrum and intensity means extremely expensive lightening installation and high development costs. The solution is in the use of natural light when available. Even distribution of temperatures in the plant canopy means very expensive insulated partitions between the cultivation room and the environment, and the use of expensive air-conditioning installations. The solution is in the use of natural heat on disposal (solar radiation) and the use of acceptable cheap heating installations.

The general solution using transparent partitions between two climates has been accepted. It allows the capture of the available natural light and particularly the energy part of it.

Unfortunately, such a partition cannot be a real barrier between two different climates. It allows light, heat and air transfer between them and, in that way, makes them interdependent. The outside climate becomes an active participant in the creation of the inside one.

With such pre-conditions, a rather simple physical quantity composed of three parameters (T_a, CO_2 and H_2O) which are depended on the fourth one (I) with known characteristics, becomes extremely complicated. Even nonenergy parameters change the character of energy producing ones. For example, to keep the necessary CO_2 concentration, it is necessary to ventilate the greenhouse (heat loss) or to produce it in an artificial way (heat gain); to keep the necessary air humidity, it is necessary to ventilate the greenhouse (heat loss or gain) or to make artificial humidification (heat loss); etc. Optimal CO_2 concentration depends on the light intensity and temperatures. Higher temperatures--higher CO_2 concentration (i.e., additional ventilation and temperature drop as a consequence of the outside colder air). Higher inside temperatures provoke stronger photosynthesis activity, which means higher plant transpiration (i.e., higher air humidity) then necessary and requiring additional ventilation, which means temperature drop (additional heating is necessary).

These make the greenhouse climate a complicated physical quantity with the following characteristics:

- Composed of the long list of parameters of the inside and outside greenhouse environment. They are interdependent between themselves in very different and often opposite ways;

- All the involved parameters are directly or indirectly of an energy nature. They cause or are the reason for creation of energy transfers in the greenhouse and to its environment, and

- Taking into account that all the parameters which are directly involved in the process of photosynthesis depend on the light characteristics and intensity, greenhouse climate is of a changeable nature:

$$GK = F(t) \qquad (4)$$

Two very important conclusions can be extracted from that:

- The composition of optimal conditions for the plant development ("optimal greenhouse climate") involves a long list of influencing parameters with different influence on the crucial ones and different inertia to the short-time changes of light conditions on disposal. Therefore, one can speak not about "optimal climate," but about "optimal compromise" of influencing factors to the plant life conditions, and

- Even if the nature and interdependencies of the parameters of the greenhouse climate are known, it is not possible to define a final mathematical expression of it because some illogical "estimations" are involved.

  They cause the following consequences:

- One dimensional mathematical expression of "greenhouse climate" and, therefore, "optimal greenhouse climate" doesn't exists. It is always a set of expressions defining different physical quantities of known mutual interdependencies, and

- Composition of the optimal compromises is always connected to a chosen number of influencing parameters, in order to simplify the calculations and the selection of installations and equipment for the greenhouse climate creation. Usually, that is the internal air temperature, CO_2 concentration and air humidity, which depend on the light intensity available. The necessary corrections, connected to the plant, construction, installations and local climate specifics are determined by empirical simulations, based on the previous investigations.

It is very important to always have in mind that even the greenhouse climate is composed of energy parameters and, therefore, it is of an energy nature. Its real nature is biological and complex.

Any mathematical expression of it gives only an approximation. It is never, and cannot be complete and precise.

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THE GEYSERS PIPELINE PROJECT

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ABSTRACT

A unique public/private partnership of local, state, federal and corporate stakeholders are constructing the world's first wastewater-to-electricity system at The Geysers. A rare example of a genuinely "sustainable" energy system, three Lake County communities will recycle their treated wastewater effluent through the southeast portion of The Geysers steamfield to produce approximately 625,000 MWh annually from six existing geothermal power plants. In effect, the communities' effluent will produce enough power to indefinitely sustain their electric needs, along with enough extra power for thousands of other California consumers. Because of the project's unique sponsorship, function and environmental impacts, its implementation has required: 1) preparation of a consolidated state environmental impact report (EIR) and federal environmental impact statement (EIS), and seven related environmental agreements and management plans; 2) acquisition of 25 local, state, and federal permits; 3) negotiation of six federal and state financial assistance agreements; 4) negotiation of six participant agreements on construction, operation and financing of the project, and 5) acquisition of 163 easements from private land owners for pipeline construction access and ongoing maintenance. The project's success in efficiently and economically completing these requirements is a model for geothermal innovation and partnering throughout the Pacific Rim and elsewhere internationally.

PROJECT ORIGINS

Like many areas in California, growth in Lake County has strained its public infrastructure, including County-operated wastewater systems. In the 1980s, the Lake County Sanitation District (LACOSAN), which provides sewer service to the communities of Clearlake, Lower Lake, and Middletown, found its wastewater systems deficient in terms of both treatment quality and disposal capacity. These deficiencies prompted the state to order LACOSAN to upgrade its treatment process and find a means of disposing of larger quantities of effluent. Finding environmentally-acceptable and affordable solutions for these requirements was not easy, and LACOSAN spent several years evaluating alternative treatment and disposal options, including agricultural irrigation, created wetlands, and ultimately geothermal injection.

At the same time in the late 1980s, the region's geothermal power industry began to experience productivity declines in The Geysers steamfield. Power plant steam usage was exceeding the steamfield's natural recharge rate and steam production was falling dramatically. The geothermal heat source remained constant; but, injection of additional water was needed to convey the geothermal heat to steam production wells. With the support of the California Energy Commission and Geysers operators, a joint Lake and Sonoma County survey was conducted of potential injection water sources available in The Geysers region, including surface waters, groundwater, and municipal wastewater. This study concluded that surface and groundwater supplies were already over committed; but, the wastewater effluent could satisfy two critical needs at once--first, as an environmentally-superior wastewater disposal method, and second, as a continuous supply of steamfield recharge water that could help mitigate Geysers productivity declines.

DEVELOPMENT PROCESS

Once the project concept emerged, a group of key stakeholders convened to investigate its feasibility and pursue project development. The core group included LACOSAN, the Northern California Power Agency (NCPA), Calpine Corporation, Unocal Corporation, and Pacific Gas & Electric Company (PG&E). The group pursued four simultaneous tracks of project development during 1991-96:

- Technical. A series of geothermal reservoir analyses and pipeline engineering studies examined reservoir impacts from effluent injection and multiple pipeline alignments and operating strategies. The results of these studies were then cost estimated and subjected to a series of life-cycle economic analyses. Together with the environmental track described below, this process iterated to a final design concept and working cost estimate;

- Environmental. Along with reservoir and pipeline technical studies, preliminary environmental surveys were performed to build a database and identify possible design and construction conflicts with environmental resources. An explicit strategy from the outset was emphasis on early identification of environmental issues, quick preparation of documentation for objective evaluation of those issues, and design coordination to then avoid significant sensitivities before they could become impediments or controversies. The environmental track concluded with the preparation of the project EIR/EIS;

- Legal. Over the course of the technical and environmental reviews, the stakeholders also negotiated an initial agreement-in-principle for overall project development, and then detailed construction, operating, and related financing and water supply agreements, and

- Financial. The group members were also engaged at the same time in securing their individual construction cost shares and raising construction funds from public agencies with allied program goals.

As finally designed, the project consists of a 29-mile, 20-inch diameter pipeline that will carry 7.8 million gallons per day of treated wastewater effluent and Clear Lake make-up water to The Geysers for injection at existing wells operated by NCPA, Calpine and Unocal. Figure 1 summarizes the 29-mile route from Clear Lake to The Geysers. Make-up lake water will be used to take maximum advantage of pipeline capacity during the early years of the pipeline's life; as effluent flows increase over time with population growth, make-up lake water quantities will be reduced proportionately. To move the effluent and lake water, the pipeline will use six pump stations totaling 7,370 hp, including a 1,600 ft final lift from the Bear Canyon operator and entrance up to the injection area in the southeast Geysers. Depending on steam recovery rates for the injected effluent, the project is expected to create up to 70 MW of generating capacity at six existing power plants operated by NCPA and PG&E, or as much as 625,000 MWh annually.

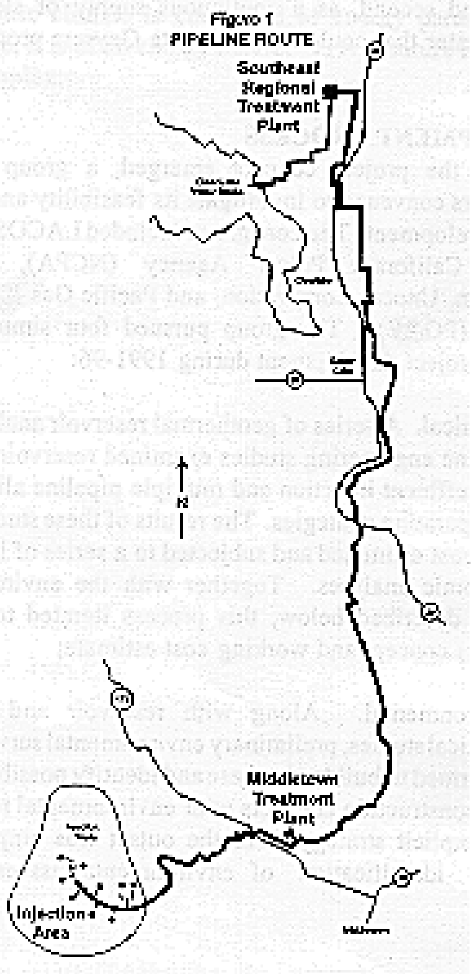

Figure 1.

The project's total construction cost is $45 million, including $8 million in wastewater treatment plant improvements. Construction costs are being shared by the core group of participants, known as the Joint Operating Committee (JOC), with additional funding from the California Energy Commission, California Water Resources Control Board, U.S. Department of Energy, U.S. Department of Commerce, U.S. Department of the Interior, and the U.S. Environmental Protection Agency. Approximately 40% of the construction costs are industry-funded, 20% are County funded, and the remaining 40% is divided equally between economic development and energy resource funds from the federal and state agencies. Additionally, the industry participants are investing several million dollars in secondary pipelines terminus to injection wells in the steamfield.

The project's annual operating costs are estimated at approximately $1.5 to 2 million. The JOC members have signed a 25-year operating agreement wherein LACOSAN will operate the pipeline as far as the Middletown area, after which it will be industry-operated to its terminus in the steamfield. LACOSAN will pay an annual O&M cost share equivalent to its normal disposal costs, with the industry participants paying the remaining O&M costs based on the quantity of effluent they each receive at their wellheads.

PERMITS AND AGREEMENTS

A major aspect of the project from the outset was its institutional complexity, and the need to reach legal and administrative agreement with numerous public and private stakeholders representing a myriad of environmental, regulatory, operator, and property interests. Table 1 summarizes the project's five major categories of institutional requirements, and the specific permits and other items that were completed, negotiated, and/or acquired during 1991-96.

Initially, considerable effort was devoted to negotiating agreement among the JOC members to pursue project development. This was embodied in a 1991 agreement-in-principle that set out the project's basic goals and committed stakeholders to consensus decision making. Extensive effort also went into negotiating federal geothermal royalty reduction agreements that allow lower industry royalty payments in exchange for larger industry construction cost shares, plus a longer overall term of payments as a result of the effluent-extended reservoir life. A critical agreement also had to be negotiated with adjacent Yolo County for a portion of

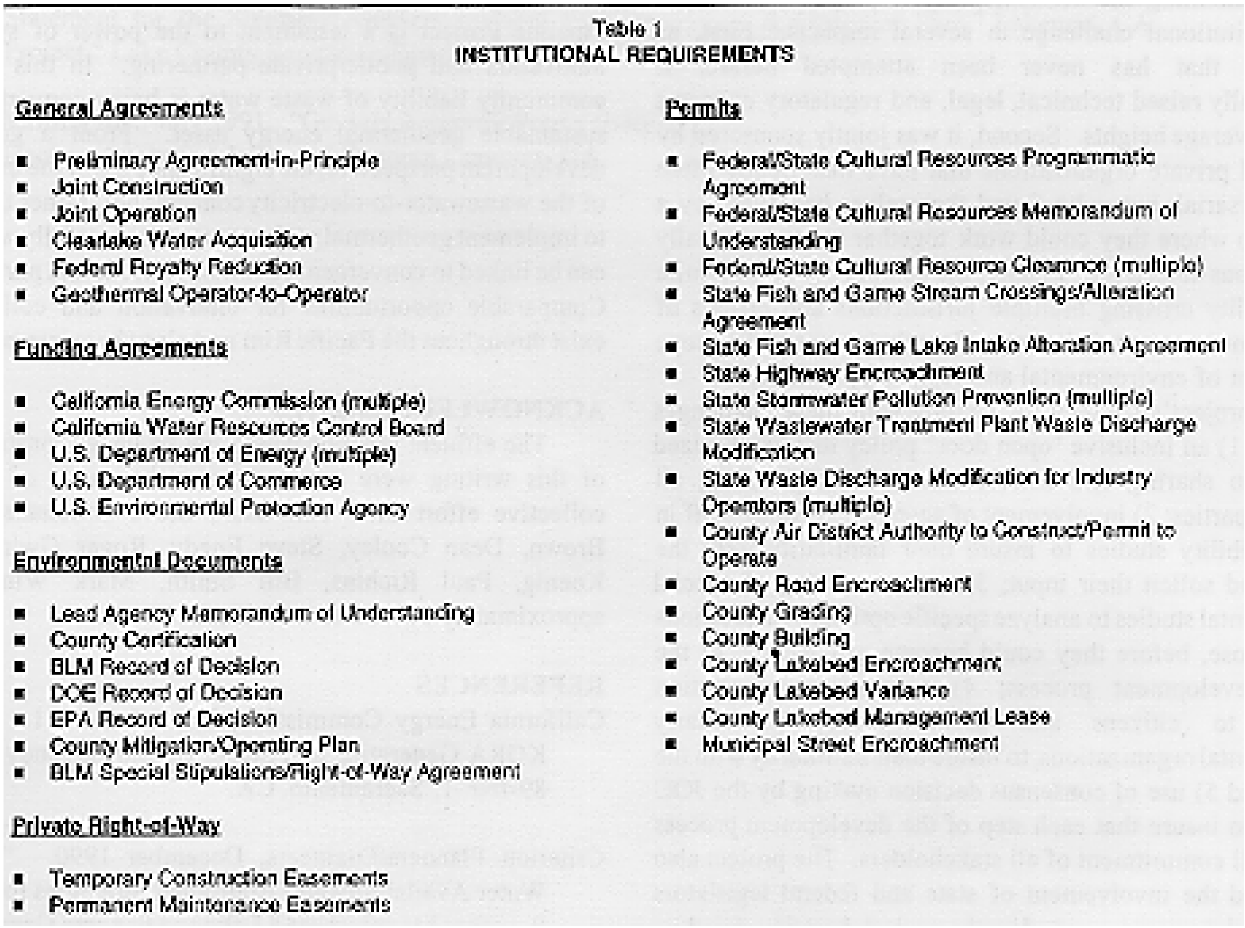

Table 1
INSTITUTIONAL REQUIREMENTS

General Agreements

- Preliminary Agreement-in-Principle
- Joint Construction
- Joint Operation
- Clearlake Water Acquisition
- Federal Royalty Reduction
- Geothermal Operator-to-Operator

Funding Agreements

- California Energy Commission (multiple)
- California Water Resources Control Board
- U.S. Department of Energy (multiple)
- U.S. Department of Commerce
- U.S. Environmental Protection Agency

Environmental Documents

- Lead Agency Memorandum of Understanding
- County Certification
- BLM Record of Decision
- DOE Record of Decision
- EPA Record of Decision
- County Mitigation/Operating Plan
- BLM Special Stipulations/Right-of-Way Agreement

Private Right-of-Way

- Temporary Construction Easements
- Permanent Maintenance Easements

Permits

- Federal/State Cultural Resources Programmatic Agreement
- Federal/State Cultural Resources Memorandum of Understanding
- Federal/State Cultural Resource Clearance (multiple)
- State Fish and Game Stream Crossings/Alteration Agreement
- State Fish and Game Lake Intake Alteration Agreement
- State Highway Encroachment
- State Stormwater Pollution Prevention (multiple)
- State Wastewater Treatment Plant Waste Discharge Modification
- State Waste Discharge Modification for Industry Operators (multiple)
- County Air District Authority to Construct/Permit to Operate
- County Road Encroachment
- County Grading
- County Building
- County Lakebed Encroachment
- County Lakebed Variance
- County Lakebed Management Lease
- Municipal Street Encroachment

their water rights to Clear Lake for the make-up water needed during the project's early years when effluent flows will be relatively small in relation to pipeline capacity. Another set of agreements and special legislation were arranged for financial assistance provided by state and federal agencies.

In order to structure the project's environmental review, a memorandum of understanding was negotiated between the BLM, who administers federal geothermal leases held by Calpine and NCPA, and LACOSAN as the primary local sponsoring agency. BLM was designated as the lead agency for federal environmental review and LACOSAN was designated as the lead agency for state environmental review. Once underway, the EIR/EIS process focused on effluent injection-induced seismicity, possible groundwater contamination from effluent injection, sensitive plants impacts from pipeline construction, sensitive stream crossings by the pipeline, archaeologic site impacts, and Clear Lake water quality impacts. Analysis of these and other environmental issues revealed no significant adverse impacts that could not be adequately mitigated.

Following the preparation and certification of the EIR/EIS, records of decision were prepared for BLM, as well as DOE and EPA because of their funding roles. LACOSAN also prepared a detailed Mitigation, Monitoring and Operating Plan (MMOP) as required by state laws to insure that pipeline construction and operations comply with the mitigations stipulated in the EIR/EIS, and that the project continues to function in an environmentally-acceptable manner over its operating life. A separate set of BLM environmental stipulations was also negotiated to ensure that pipeline construction and operations on federal lands are similarly compliant with the EIR/EIS. As an example of the project's attention to both environmental soundness and public involvement, one of the MMOP measures was establishment of a seismic monitoring advisory committee whose citizen and industry members will regularly examine seismic data for any indication of effluent-induced activity.

Permitting of the project was organized according to five segments, or reaches, of the pipeline. For each reach, a variety of local, state, and federal permits were required depending upon the urban or rural character of the reach and the presence or absence of sensitive environmental resources. Of the project's total 25 permits, the major ones included: federal and state archaeologic clearances, state fish and game authorizations for sensitive stream crossings and the Clear Lake intake, public highway and road encroachments, construction storm-water pollution prevention, and air quality management.

Finally, in addition to public right-of-way encroachments, easements had to be obtained from 163 private land owners over the 29-mile pipeline alignment for construction and ongoing maintenance access.

CHALLENGES AND ACCOMPLISHMENTS

Implementing the effluent pipeline project has been a major institutional challenge in several respects. First, as something that has never been attempted before, it automatically raised technical, legal, and regulatory concerns to above average heights. Second, it was jointly sponsored by public and private organizations that have historically often been adversarial; but, who found themselves benefitted by a partnership where they could work together toward mutually advantageous objectives. Finally, the complexity of a 29-mile linear facility crossing multiple jurisdictions and dozens of sensitive environmental sites significantly increased the scope and amount of environmental and regulatory scrutiny.

The project's strategy for dealing with these challenges included: 1) an inclusive "open door" policy that emphasized information sharing and collaborative planning among all interested parties; 2) involvement of agency permitting staff in early feasibility studies to insure their familiarity with the project, and solicit their input; 3) commissioning of special environmental studies to analyze specific options and questions as they arose, before they could become problematic to the project development process; 4) aggressive information outreach to citizens and civic groups, particularly environmental organizations, to insure their familiarity with the project; and 5) use of consensus decision making by the JOC members to insure that each step of the development process had the full commitment of all stakeholders. The project also emphasized the involvement of state and federal legislators whose districts were impacted by the project, insuring that they were aware of the problems the project was responding to, and the benefits expected if implemented as planned.

As a result of this strategy, the project's legal and institutional accomplishments to date include:

- An EIR/EIS completed and certified within 18 months and without any appeals,

- All permits acquired within 18 months without any agency imposition of extra project costs or any delays to the project's schedule,

- No appeals or other legal challenges to any of the permits or project agreements, and

- All legal, institutional, and environmental work completed within or under budget, in a total amount equivalent to approximately 3.5% of project construction costs.

CONCLUSION

The project's construction ground breaking took place on October 6, 1995. As of this writing, construction is underway on all of the pipeline reaches, with completion and start-up expected in August 1997.

In an age of dwindling resources, increasing competitive pressures, and bureaucracy, the Southwest Geysers Effluent Pipeline Project is a testament to the power of synergistic innovation and public/private partnering. In this case, the community liability of waste water is being converted into a sustainable geothermal energy asset. From a geothermal development perspective, the significance is not the uniqueness of the wastewater-to-electricity concept; but, rather the ability to implement geothermal projects more successfully where they can be linked to convergent community needs and partnerships. Comparable opportunities for innovation and collaboration exist throughout the Pacific Rim and elsewhere internationally.

ACKNOWLEDGMENTS

The effluent pipeline would not be under construction as of this writing were it not for the thousands of hours of collective effort of: Tom Box, Steve Brodnansky, Gary Brown, Dean Cooley, Steve Enedy, Roger Gwinn, Brian Koenig, Paul Richins, Bill Smith, Mark Winsor, and approximately 300 other individuals.

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GEOTHERMAL PIPELINE

Progress and Development Update
from the Geothermal Progress Monitor

WYOMING

Biotech Companies Profit from Yellowstone Hot Springs

Yellowstone's more than 10,000 geysers, hot springs, mud pots and fumaroles awe and delight 3 million park visitors each year. They are also drawing the interest of biotechnology companies and academic researchers like Ward, a professor at Montana State University, and Ramsing, a postdoctoral student. Long thought to be too hot and harsh to sustain any form of life, the park's geothermal attractions contain an astonishing variety of micro- organisms, whose ability to survive both high temperatures and extremes of acidity and alkalinity--from battery acid to household ammonia--makes them potentially valuable.

The spur for this biological gold rush is *Thermus aquaticus*, discovered in the nearly boiling waters of Mushroom pool, about 8 miles from Old Faithful. An enzyme from Taq, as the microbe is known, drives the polymerase chain reaction, or PCR. This laboratory genecopying process in turn makes possible DNA fingerprinting, which has revolutionized the study of blood and other evidence in criminal investigations. Cetus, the company that patented Taq and the PCR technique, sold them for $300 million in 1991 to Hoffmann-LaRoche, which now earns more than $100 million a year from sales of the process.

While the Taq Enzyme has proved to be a microbial mother lode. Yellowstone thermophiles are being used in other commercial applications as well. These include converting organic wastes like cellulose into ethanol and other fuels, producing an environmentally safe road de-icer and a non-toxic paint stripper for military aircraft, and various genetic engineering projects. They also are used in pulp and paper processing, gold and copper mining, acid mine drainage and reclamation, food processing and the perfume industry. And scientists from the National Aeronautics and Space Administration are studying the geothermal features as a possible model for evidence of past life on Mars.

About 40 universities and private laboratories hold permits to hunt for the thermophiles in Yellowstone's bubbling primordial pools. Researchers liken the vast, largely untapped microbial ecology of the park's hot springs to the incredible biodiversity of the Brazilian rain forest. "The biotechs are hunting hard, hot and heavy," says Ward, who also serves as a kind of guide for companies wanting to prospect the pools. "Everyone wants to discover another *Thermus aquaticus*."

Though Yellowstone's $20-million budget for next year isn't enough to prevent cutbacks in visitor services or to repair some of the national park system's worst roads, the cash-strapped park has yet to see a dime of the hundreds of millions of dollars Hoffmann-LaRoche and other biotech companies have made from its microbes. The federal government, which sells timber from the national forests and profits from royalties paid on oil, gas and coal leases on public lands, has no similar provisions for selling micro-organisms; although, it is angling for a share of the potentially immense future profits.

Academics on tight budgets fear that being forced to pay for the privilege of doing basic research in a public park could crimp their efforts. But park officials and some biotech companies eager to claim rights to any valuable new discoveries think Yellowstone should be able to cash in on its unique resource. The park's chief scientist, John Varley, wants biotech companies to pay a royalty of 0.5 percent to 1.5 percent on new discoveries. For the park, that could turn billions of tiny organisms into gold. (Source: *U.S. News & World Report*, December 2, 1996)