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FUTURE AIR QUALITY MAINTENANCE AND IMPROVEMENTS THROUGH THE EXPANDED USE OF GEOTHERMAL ENERGY

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ABSTRACT

Geothermal development projects have experienced considerable slow down due to a combination of factors including the State of California change from a deficit to a surplus electrical generator and the low cost of imported oil. Environmental factors which are estimated to combine to change this situation and stimulate future geothermal growth are presented.

The association between energy use and production and global air pollution which is prompting local, state and federal agencies to explore alternatives to fossil fuel use is described. All forms of fossil fuel use either in stationary sources such as electrical power plants or in mobile use such as in transportation are shown to be producing unacceptable quantities of air pollutants.

The discussion includes infrared absorbing gasses, acid rain, ozone formation, hazardous waste generation and air toxics. Agencies' strategies for maintaining and improving air quality in the future are discussed. An expanded role and opportunity for geothermal energy use is forecast if its inherent environmental advantages are utilized.

INTRODUCTION: THE PROBLEM - GLOBAL AIR POLLUTION FROM FOSSIL FUEL BURNING

The Greenhouse Effect

The causes and predicted consequences of the greenhouse effect are well stated and illustrated by Gordon J. MacDonald, in the paper Scientific Basis for the Greenhouse Effect where he states:

> "Carbon dioxide and a wide variety of other gases, including methane, ozone, and freon, trap a portion of the earth's thermal radiation that would otherwise escape into space [see Figures 1 and 2]. This radiative trapping of energy produces the heating of the atmosphere popularly labeled the greenhouse effect [see Figure 3]. Detailed observations from remote stations show that the carbon dioxide concentration of the atmosphere has increased from 316 parts per million by volume (ppmv) in 1958 to 350 ppmv in 1986. The exponential growth in carbon dioxide levels parallels the increased worldwide use of carbon-based fuels [see Figure 4]. Methane concentrations are increasing at a rate of one to two percent per year, lower atmosphere ozone at a somewhat smaller rate, and freon at a current rate of five percent a year. Calculations of the expected increases in the average temperature of the earth's surface since 1900 lead to a value of about 0.5 C (0.9 F) if the moderating effect of the earth's oceans is taken into account. Calculations are based on models that range in complexity from simple energy balance considerations to detailed three-dimensional calculations that strain the capacity of current digital computers. Detailed analysis of tens of millions of surface-temperature observations indicate an average warming of about 0.5 C (0.9 F) since the turn of the century and a greater warming of 2 C (4 F) in high latitudes. Major climatic shifts can be expected as the warming proceeds at an increasing pace. The rate of anticipated warming is historically unprecedented" (MacDonald, 1988).

MacDonald and other researchers have laid the scientific and policy basis for interpretation of the effects associated with infrared inhibiting atmospheric pollutants.

The world wide increase in the use of fossil fuels by percentage of contribution is shown in Figure 5 which illustrates the dramatic increased use in developing countries. Questions concerning the validity of the consequence of the measured atmospheric concentrations of carbon dioxide do not dispute the levels, rather the question is, what will be the result of the increases. The world wide temperature differences between glacial periods and interglacial periods average an estimated 5 C (9 F) (Flohn, 1975). The estimated

Figure 1. Historical variations in atmospheric carbon dioxide concentration

Data from 1958 to the present are from Keeling's observations at Mauna Loa, Hawaii.[3] Data for the 1740 to 1956 period are taken from measurements of air trapped in glacial ice sheets.[3]

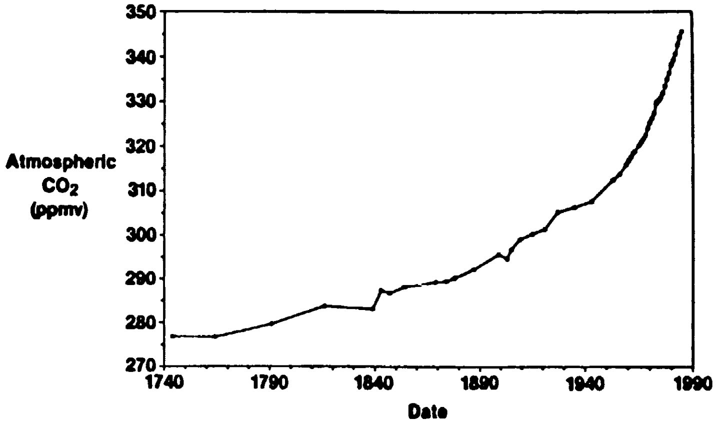


Figure 2. Historical variations in carbon dioxide emission from the burning of fossil fuels (data from Rotty[7] and Keeling[8])

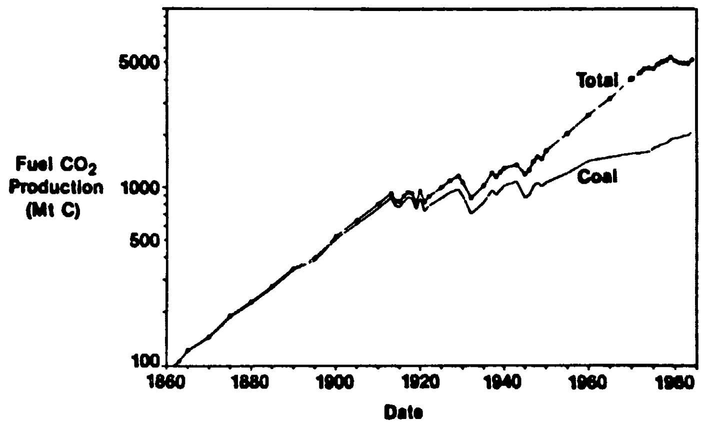
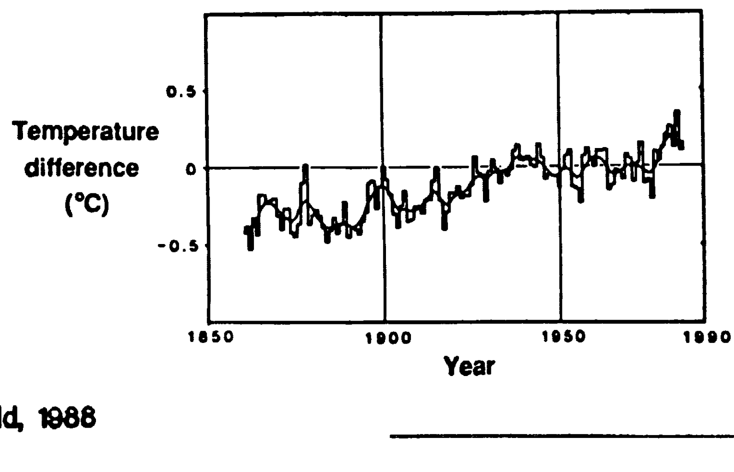


Figure 3. Annual variation of global mean temperature from 1861 to the present (after Jones, Wigley and Wright[11])



SOURCE: MacDonald, 1988

Figure 4. Variations in the contribution of various fuels to global carbon dioxide emissions

The natural gas curve includes contributions from gas that is flared at the well. The amount of flared gas has decreased with time so that the amount of gas used for energy has increased at a greater rate than the figure indicates. Data are based on Rotty's analysis of United Nation data compilations.[14]

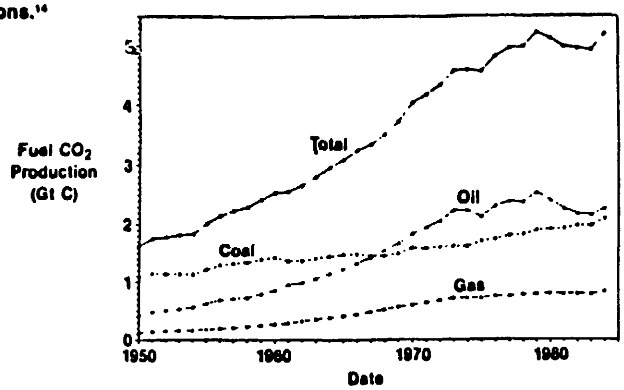


Figure 5. Changes in fractional contribution to global CO_2 emissions by major regions of the world

Eastern Europe refers to the centrally planned economies of eastern Europe, including all of the Soviet Union. C P Asia includes the centrally planned economies of Asia, China, North Korea, Mongolia, North Vietnam, etc. Japan, Australia and New Zealand comprise the Pacific region.

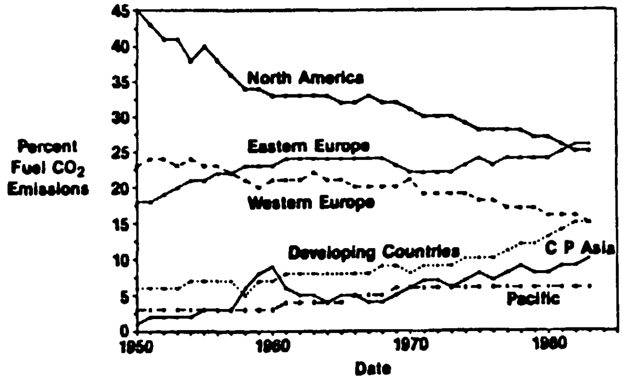
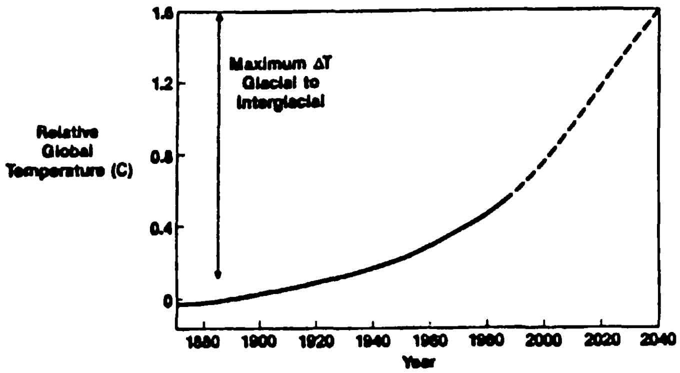


Figure 6. Past and future changes in global mean temperature

Changes are from addition of carbon dioxide to the atmosphere. Other greenhouse gases will lead to funher temperature increases in the future.



SOURCE: MacDonald, 1988

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relative global increases are shown in Figure 6 and indicate that the greenhouse gases have already contributed to 0.5 C (0.9 F) and are estimated to continue rising (MacDonald, 1988).

Acid Rain

The release of sulfur compounds by fossil fuel burning in Europe led to observations of decreased pH levels in rain in the late 1960's (Brodine, 1971). The "acid rain" effect has been widely documented in the United States and Canada. States such as California have responded to the results of acid deposition monitoring through legislative acts such as the Kapiloff Act of 1982. Acid deposition monitoring in California has documented wide acidic effects caused by fossil fuel burning and vehicular emissions of nitrogen oxides (CARB, 1988). The effects of particulate emissions caused by fossil fuel burning both directly and as precursors add materially to the mounting problem of maintaining acceptable and safe levels of airborne sulfur oxide particulates.

Ozone Formation

There is increasing pressure on regulators to find ways of maintaining and improving ambient air quality especially in large urban areas. Increases in air emissions from stationary and mobile sources have increased the incidence of concentrations of criteria pollutants, especially ozone, beyond ambient air quality standards. Carbon monoxide (CO) and nitrogen oxides (NOx) are precursors which under photochemical processes form ozone. Present strategies to control ozone formation consist of improved NOx control.

Agency Response

The most comprehensive response to the increasing problem of decreases in air quality are found in the California Clean Air Act, Sher AB2595. The Act mandates the California Air Resources Board to determine which air basins are nonattainment and which air basin pollutant transports are affecting the attainment status of other basins. Areas of nonattainment must formulate a plan for achieving attainment by 1991. Heavy equipment, indirect and area wide sources are to be considered in the attainment plans. Special considerations are given to the South Coast Air Basin and reduction of vehicular emissions. Reduction of major sources, 500 tons/yr (114 lb/hr) is required. Review of Permits to Operate as they need renewal is required.

While electrical power is deemed the preferred "clean" fuel, fossil fueled power plants near or within urban areas are and will increasingly pay extra costs for their Air Emissions Control Systems (AECS) (SCAQMD, 1988).

The South Coast Air Quality Management District, which includes the cities of Los Angeles and San Diego has recently proposed a limit to NOx emissions from electrical power generating boilers, Rule 1135, which will necessitate the retrofit of 56 plants at an estimated cost of $1.44 billion dollars. The Rule will limit emissions to 0.03 lb NOx per MMBtu heat input with costs averaging $ 42,600 per ton NOX and a range of $ 8,000 to $ 640,000 per ton NOx. This will constitute an estimated 70% reduction from present power plant NOx emissions (SCAQMD, 1988).

Hazardous Waste Generation

Dramatic and expensive changes face the Nation in the way that hazardous wastes are to be handled in the future. All hazardous wastes will be required to be dried, treated and stabilized. Depending upon the type, the treated waste may require solidification or encapsulation. These materials will be stored in a repository with no liquids accepted. The California program is an example of what will affect all electrical power plants which produce hazardous wastes from their required emissions control systems. The California Legislature passed AB 2948 (Tanner, 1986)

> "to insure that safe, effective, and economical facilities for the management of hazardous wastes are available when they are needed, and that these facilities are of a type, and operated in a manner, which protects public health and environment.
>
> "The Federal Resource Conservation and Recovery Act (RCRA)(1), the Hazardous and Solid Waste Amendments (HSWA) of 1984(2) and state statutes enacted in California in 1985(3) and 1986(4) mandate an immediate and dramatic improvement in the way nonradioactive(5) hazardous waste is managed in the nation and California. These statutes will prohibit the land disposal of untreated hazardous waste after May 8, 1990.
>
> "To achieve this improvement in hazardous waste management, manufacturers and users of commodities and resources must take measures to minimize hazardous waste production. The remaining volume of hazardous waste will require new types of hazardous waste management facilities to be established. These facilities may include recycling and treatment facilities, residual repositories for treated

residues and hazardous waste transfer and storage facilities." (CDHS, 1987)

One of the leaders in geothermal power development, The Geysers KGRA in Northern California, while producing much less hazardous waste than their fossil fueled alternative, still will average in the future an estimated 7.7 ton of hazardous waste per MWe-yr. The majority of the hazardous waste produced at The Geysers is generated by chemical abatement, the Stretford and the Dow RT-2 burner-scrubber AECS.

A study of the application of noncondensable gas injection, incineration and flash suppression with the goal of reducing hazardous waste generation is in progress (see Goddard, W.B., C.B. Goddard and D.W. McClain, Hazardous Waste Reduction Potential of Noncondensable Gas Injection, Incineration, and Flash Suppression in Geothermal Power Plant Air Emissions Control Systems - A Technical Feasibility Study Progress Report). The study is designed to document the success that has been demonstrated at the Coso KGRA by California Energy Company that through the use of noncondensable gas injection considered BACT by the local air district, that a geothermal steam plant can operate with very low emissions of hydrogen sulfide without the use of hazardous materials.

The Stretford hydrogen sulfide abatement system produces about 80% of the present hazardous waste generation in Lake County geothermal power plants. It has been demonstrated that this can be reduced to an estimated 3.7% by improved sulfur recovery and careful Stretford operation. Waste Oil and Solvents surveyed averaged 0.036 ton/MWe-yr (LCPD, 1989).

Air Toxics And Hazardous Waste Generation

Air toxic emissions, inherent with hazardous waste generation, are coming under closer scrutiny by regulatory agencies. Fossil fueled electrical power plants producing air toxics will pay additional environmental penalties in the future. The California Air Toxics legislation is an example.

The California Assembly, responding to the needs and desires of the public and industry, passed AB 1807 the Tanner Bill in 1983 which is now Section 39650 of the California Health and Safety Code. The law requires the California Air Resources Board (CARB) to submit candidate toxic air contaminants to the California Department of Health Services (CDHS) for their health effects review. Candidate toxics considered to pose serious health effects are then passed on to an Independent Scientific Review Panel for further review. CARB must then hold public hearings on the candidate toxics as per their addition to the toxic air borne substance list and the proposed concentration standard.

Alternative energy sources such as geothermal energy can supply "clean" electrical power without the production of NOx or appreciable quantities of methane, CO or carbon dioxide. The following section compares carbon oxides emission of various fuel sources including geothermal energy.

THE SOLUTION - USE OF ALTERNATIVE RENEWABLE ENERGY SOURCES SUCH AS GEOTHERMAL ENERGY

Carbon Dioxide Emission Comparison - Geothermal to Fossil Fuel

It is clear that every major urban center and industrial complex globally is emitting unacceptable quantities of climate modifying air pollutants into the atmosphere. Strategies which allow high standards of living without fossil fuel burning must include technologies that produce electrical energy which have little or no carbon dioxide, nitrogen or sulfur oxides, or particulate emissions. These technologies include solar energy, hydroelectric and geothermal energy.

Typical carbon dioxide emissions in lb/hr per megawatt electrical (MWe) for various fuel sources are listed in Table 1. Carbon dioxide emissions from the Air Emissions Control Systems (AECS) used at The Geysers, California by geothermal power plants average 21.9 lb/hr MWe (expressed as carbon) or 7.7% of methane while geothermal power plants using noncondensable gas injection AECS have the lowest emission rate of 0.327 lb/hr MWe (expressed as carbon) or 0.116% of methane or 0.0618% of that of subbitumous coal. California Energy Company, Inc. has pioneered geothermal noncondensable injection AECS at Coso. This system has the lowest hydrogen sulfide emissions rate for a steam powered wet tower plant in the world.

Sulfur Oxides Emission Comparison - Geothermal to Fossil Fuel

Solution of the acid rain problem will increasingly limit the use of power plant technologies which are not capable of extremely low sulfur emission rates. Geothermal power plants have lower total sulfur emissions than their fossil fuel alternatives as shown in Table 2. The geothermal plants utilizing injection in

TABLE 1

COMPARISON OF CARBON DIOXIDE EMISSIONS
FROM DIRECT COMBUSTION IN POWER PLANT OPERATIONS

Power Plant Fuel Source	Carbon Dioxide Emissions per Megawatt Electrical (expressed as lb Carbon)(d)	Percentage of Methane
	lb/hr MWe(e)	%
Methane (e)	282	100
Ethane (e)	324	115
Propane (e)	341	121
Butane (e)	351	124
Gasoline (e)	395	140
Diesel Oil (e)	412	146
Fuel Oil #6 (e)	418	148
Bituminous Coal (e)	497	176
Subbituminous Coal (e)	529	188
Geothermal		
The Geysers (a, f)	21.9	7.77
PG&E Unit 20 (b, f)	21.9	7.77
Coso injection (c, f)	0.327	0.116

Notes:

(a) Average of The Geysers 24 Geothermal Power Plants currently operating with a combined output of 1773 MWe, AECS including chemical, Stretford and Dow Scrubber-Burner;

(b) PG&E Unit 20 with an output of 113 MWe, AECS Stretford;

(c) Average of the 9 CECI Coso units, 8 under construction and Navy-1 operating, with a combined estimated output of 225 MWe, AECS utilizing noncondensable gas injection;

(d) Studies of the "Greenhouse" effects traditionally express carbon dioxide as pounds of carbon. Multiple by 44/12 to approximately obtain lb/hr of carbon dioxide;

(e) Following USEPA conversions were used in the calculations: 250 MM Btu/h heat input is equal to 29 MWi heat input, or 25 MWe output, or 200,000 lb steam/h output

(f) Performance test measurements

Sources:

MacDonald, 1988
Goddard, 1988
Goddard, 1987
Truesdall, 1987
BLM, 1988

GODDARD & GODDARD ENGINEERING, 1988

TABLE 2

COMPARISON OF CONTROLLED POWER PLANT SULFUR EMISSIONS

OF FOSSIL FUEL FIRED AND GEOTHERMAL POWER PLANTS

Power Plant	Hydrogen Sulfide Emissions per Megawatt lb/hr MWe	Sulfur Oxides per Megawatt lb/hr MWe
The Geysers Average (a, h)	0.242	0.455 (g)
PG&E Unit 20 (b, h)	0.0920	0.173 (g)
CECI Coso injection (c, h)	0.0662	0.124 (g)
Coal (d, f)		12.0
Oil (e, f)		10.6

Notes:
(a) Average of The Geysers 24 Geothermal Power Plants currently operating with a combined output of 1773 MWe, AECS including chemical, Stretford and Dow Scrubber-Burner;
(b) PG&E Unit 20 with an output of 113 MWe, AECS Stretford;
(c) Average of the 9 CECI Coso units, 8 under construction and Navy-1 operating, with a combined estimated output of 225 MWe, AECS utilizing noncondensable gas injection;
(d) Tennessee Valley authority 12/13/86 USEPA #KY-0007B, 200 MMBtu/hr boiler (20 MWe equivalent);
(e) Georgia-Pacific Corp. USEPA #OH-0094, 118 MMBtu/hr boiler (30.9 MWe equivalent);
(f) Following USEPA conversions were used in the calculations: 250 MM Btu/h heat input is equal to 29 MWi heat input, or 25 MWe output, or 200,000 lb steam/h output;
(g) SOx as SO2 after 18 to 30 hours (Weres, 1977).
(h) Performance test measurements

Source:
Truesdall, A.H., et al, 1987
Goddard, 1988
USEPA 1987 BACT/LAER

GODDARD & GODDARD ENGINEERING, 1988

NOTES ON HAZARDOUS WASTE LEGISLATION

(1) Public Law 94-580
(2) Public Law 98-616
(3) Senate Bill 509, Carpenter/Assembly Bill 1809, Sher
(4) Senate Bill 1500, Roberti/Assembly Bill 2948, Tanner
(5) Radioactive wastes are regulated by the Federal Government.

their AECS have sulfur oxides emission rates 1.03% that of coal or 1.17% that of oil. The geothermal plants using injection achieve this distinction without the use of hazardous materials in their AECS.

Particulate Emissions Comparison - Geothermal To Fossil Fuel

Comparison of the particulate emission rates of geothermal plants to fossil fuel fired plants is hampered since geothermal plants have no equivalent of "stack" emissions. All power plants using wet cooling towers have particulate emissions which are significant when their make-up water is high in Total Dissolved Solids (TDS).

Geothermal power plants use condensed steam (single distilled water) which is very low in TDS for cooling tower make-up water. This results in very low particulate emissions rates from their wet cooling towers. Rates of particulate drift from cooling towers at Coso are estimated at <0.001 lb/hr MWe. Typically, controlled coal, oil and biomass stack emission rates are in the order of 1 lb/hr MWe.

CONCLUDING REMARKS

The Geothermal industry has an unprecedented opportunity to make use of it's environmentally "clean" electrical energy production. The geothermal industry must explain their "clean" electricity to regulating agencies, urban planners and others who are attempting to manage air resources so that mandated improvements in air quality will occur in the future.

The authors are convinced that a preferred position based on the environmental factors can be obtained by the geothermal industry if it will work toward maintaining it's superior environmental record and project this information to the appropriate agencies.

REFERENCES

BLM, 1988
Draft Environmental Assessment/ EIR for the California Energy Company Proposed Plans of Utilization, Development, and Disposal for Geothermal Development on BLM Geothermal Lease CA-11402, Coso KGRA, Inyo County, CA Table 1.5-3. BLM and GBUAPCD, Feb. 1988, McClenahan and Hopkins Assoc., San Mateo and Kensington, CA.

:ARB, California Air Resources Board, eptember 1988
he Health and Welfare Effects of Acid eposition in California, An Assessment, DRAFT, State of California Air Resources Board, Research Division, Sacramento, CA.

CDHS, 1987
Guidelines for the Preparation of Hazardous Waste Management Plans, California Department of Health Services, Toxic Substance Control Division, Sacramento, CA.

Flohn, Hermann, 1975
Background of a Geophysical Model of the Initiation of the Next Glaciation, in Climate of the Arctic, pages 98 to 110, 24th Alaska Science Conference, Univ. of Alaska, 1973.

LCPD, (Lake County Planning Dept.) 1989
Lake County Hazardous Waste Management Plan, prepared by Brown, Vence and Associates, San Francisco, with Goddard & Goddard Engineering, Upper Lake, CA.

Goddard, W.B. and C.B. Goddard, 1988
Balancing Test, California Energy Company, Inc.'s Application for a Small Power Plant Exemption for the COSO Navy 2 Geothermal Project, Marron, Reid & Sheehy, Sacram., CA.

Goddard, W.B. and C.B. Goddard, Dec. 1988
DEIR Air Resources Section, Freeport-McMoRan Resources Partners Limited Partnership Geysers Geothermal Company, West Ford Flat Power Plant Project, Lake County, for Nolte and Associates, Goddard & Goddard Engineering, Lucerne, California.

MacDonald, G.J., 1988
Scientific Basis for the Greenhouse Effect, Journal of Policy Analysis and Management, Vol. 7, No. 3, 425-444 (1988) by the Assoc. for Public Policy Analysis and Management, Published by John Wiley & Son, Inc.

SCAQMD, 1988
Proposed Rule 1135 - Emissions of Nitrogen Oxides from Electrical Power-Generating Boilers, Staff Report, South Coast Air Quality Management District, Rule Development Division, El Monte, CA.

Truesdall, A.H., et al, 1987
Fieldwide Chemical and Isotropic Gradients in Steam from The Geysers, Table 1, Central and West Geysers, Stanford Geothermal Reservoir Engineering Workshop, Stanford Research Inst., Jan 1987, Menlo Park, CA.

USEPA 1987
BACT/LAER Clearinghouse - a Compilation of Control Technology Determinations, second supplement to 1985 Edition, USEPA Office of Air Quality Planning and Standards, June 1987, Research Triangle Park, NC

Weres, O., K. Tsao and B. Wood, June 1977
Resource, Technology and Environment Geysers. Lawrence Berkeley Lab. USDE.