Environmental, Health, and Safety Guidelines for Geothermal Power Generation

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

These EHS guidelines apply to Geothermal Power Generation. A general description of geothermal power generation activities is provided in **Annex A** of this document. Please see the EHS Guidelines for Electric Power Transmission and Distribution for discussion of related transmission and distribution issues.

This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management
Section 2.0 — Performance Indicators and Monitoring
Section 3.0 — References
Annex A — General Description of Industry Activities

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with geothermal power generation, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Environmental issues that may occur during geothermal power generation projects, include the following[2]:

- Effluents
- Air emissions
- Solid waste
- Well blowouts and pipeline failures
- Water consumption and extraction

Effluents

Drilling Fluids and Cuttings

Steam production and re-injection wells may be installed during exploration, development, and operational activities. Drilling fluids employed during drilling activities may be water- or oil-based, and may contain chemical additives to assist in controlling pressure differentials in the drill hole and to act against viscosity breakdown. Cuttings from oil-based mud are of particular concern due to the content of oil-related contaminants and may necessitate special on-site or off-site treatment and disposal. Recommendations for the management of drill cuttings and fluids include:

- Recovery and storage of oil-based drilling fluids and cuttings in dedicated storage tanks or sumps, lined with an impervious membrane, prior to treatment (e.g. washing), recycling, and / or final treatment and disposal;
- Reuse of drilling fluid, where feasible;
- Removal of tanks or sumps to avoid the present or future release of oil-related materials into soil and water resources and treatment / disposal of contents as a hazardous on non-hazardous waste depending on its characteristics (see General EHS Guidelines);
- Disposal of water-based drilling fluids into the bore hole following toxicity assessment. Water-based cuttings are typically reused if they are non-toxic (e.g. as construction fill) or disposed of in a landfill facility;
- During acid treatment of wells, use of leak-proof well casings to a depth appropriate to the geological formation in order to avoid leakage of acidic fluids to groundwater.

Spent Geothermal Fluids

Spent geothermal fluids consist of the reject water from steam separators (rejected water is water that initially accompanies the steam from the geothermal reservoir), and condensate derived from spent steam condensation following power generation. Facilities that use water cooling towers in an evaporative process typically direct geothermal condensate into the cooling cycle. Geothermal condensate may be characterized by high temperature, low pH, and heavy metals content. Reject waters from the separators are often pH neutral and may contain heavy metals.[3] Formation steam and water quality varies depending on the characteristics of the geothermal resource.

Recommended management of geothermal fluids includes the following:

[2] Duffield and Sass (2003)

[3] Kestin (1980)

- Carefully evaluating potential environmental impacts of geothermal fluid discharges depending on the selected cooling system;[4]
- If facilities do not re-inject all geothermal fluids underground, effluent discharge quality should be consistent with the receiving water body use as described in the **General EHS Guidelines**. This may include adjusting effluent temperature according to local regulations or a site-specific standard based on potential impacts to the receiving water body. If elevated heavy metal concentrations are found in geothermal fluids, due diligence has to be exercised for their discharge into natural water bodies which may necessitate construction and operation of complex and costly treatment facilities;
- Where reinjection is the selected alternative, potential for contamination of groundwater should be minimized by installation of leak-proof well casings in the injection wells to a depth to the geological formation hosting the geothermal reservoir;
- Opportunities for reuse of reject geothermal fluids should be considered, including:
  - Use of binary power generation technology;
  - Use in downstream industrial processes if reject water quality (including levels of total and dissolved heavy metals) is consistent with the quality requirements of the intended use. Examples of downstream uses include heating applications such as greenhouses, aquaculture, space heating, food / fruit processing, and recreational use for hotels / spas, among others.
  - Final discharge of used fluids according to the treatment and discharge requirements of the applicable activity, if any, and consistent with the receiving water body use, as discussed in the **General EHS Guidelines**.

[4] Reinjection may be favored in some cases in order to prolong the life of the reservoir.

Air Emissions

Geothermal power plant emissions are negligible compared to those of fossil fuel combustion-based power plants.[5] Hydrogen sulfide and mercury are the main potential air pollutants associated with geothermal power generation employing flash or dry steam technologies. Carbon dioxide is present in the steam although its emission is also considered negligible compared to fossil fuel combustion sources. The presence and concentration of potential air pollutants may vary depending on the characteristics of the geothermal resource.

Emissions may occur during well drilling and flow testing activities, and via the open contact condenser / cooling tower systems unless pumped out of the condenser and re-injected into the reservoir along with reject geothermal fluids. Well-field and plant-site vent mufflers can also be potential sources of hydrogen sulfide emissions, primarily during upset operating conditions when venting is required. Binary and combined flash / binary technologies (with non-contact condensing technology) have close to zero emissions of hydrogen sulfide or mercury to the atmosphere because of reinjection of all geothermal fluids and gases.

Recommended methods for the management of air emissions include the following:

- Considering technological options that include total or partial re-injection of gases with geothermal fluids within the context of potential environmental impacts from alternative generating technologies together with other primary factors, such as the fit of the technology to the geologic resource and economic considerations (e.g. capital and operation / maintenance costs);

[5] For example, geothermal power plants emit approximately 1 percent of the sulphur oxide (SO_x) and nitrogen oxide (NO_x), and 5 percent of the carbon dioxide (CO_2) emissions of a thermal power plant of similar power generation capacity fuelled with coal (Duffield and Sass (2003))

- When total re-injection is not feasible, venting of hydrogen sulfide and non-condensable volatile mercury if, based on an assessment of potential impact to ambient concentrations, pollutant levels will not exceed applicable safety and health standards;
- If necessary, use of abatement systems to remove hydrogen sulfide and mercury emissions from non-condensable gases. Examples of hydrogen sulfide controls can include wet or dry scrubber systems or a liquid phase reduction / oxidation system, while mercury emissions controls may include gas stream condensation with further separation or adsorption methods;

Solid Waste

Geothermal technologies do not produce a substantial amount of solid waste. Sulfur, silica, and carbonate precipitates are typically collected from cooling towers, air scrubber systems, turbines, and steam separators. This sludge may be classified as hazardous depending on the concentration and potential for leaching of silica compounds, chlorides, arsenic, mercury, vanadium, nickel, and other heavy metals. Recommended management of hazardous waste is described in the **General EHS Guidelines** and involves proper on-site storage and containment before final treatment and disposal at an appropriate waste facility. If the sludge is of acceptable quality without significant leachable metals content (i.e. is a non-hazardous waste), on-site or off-site reuse as backfill may be considered as a potential disposal option. Recoverable solids such as sulfur cake should be recycled by third parties to the extent feasible[6]. The disposal pathways will have to be determined initially by appropriate chemical analyses of the precipitates, which should be periodically (e. g. annually) repeated to accommodate for potential geochemical variations and resulting impacts on waste quality.

Well Blowouts and Pipeline Failures

Although very rare, well blowouts and pipeline failures may occur during well drilling or facility operations. Such failures can result in the release of toxic drilling additives and fluids, as well as hydrogen sulfide gases from underground formations. Pipeline ruptures may also result in the surface release of geothermal fluids and steam containing heavy metals, acids, mineral deposits, and other pollutants.

Recommended pollution prevention and control methods to address well blowouts and pipeline ruptures include:

- Regular maintenance of wellheads and geothermal fluid pipelines, including corrosion control and inspection; pressure monitoring; and use of blowout prevention equipment such as shutoff valves; and
- Design of emergency response for well blowout and pipeline rupture, including measures for containment of geothermal fluid spills[7].

Planning for emergency response is further discussed in the **General EHS Guidelines**.

Water Consumption and Extraction

Surface water extraction is necessary for a variety of geothermal power generation activities, including well drilling, injectivity testing of subsurface formations and for use in cooling systems. Surface water used for non-contact single pass cooling is typically returned to the source with some increase in heat content, but no overall change in water quality.

The following management measures are recommended to conserve water sources used to support geothermal power generation activities:

[6] An example of a beneficial use is in the manufacture of agricultural fertilizers.

[7] For more information see Babok and Toth (2003)

- Assessing hydrological records for short and long-term variability of streams serving as source water, and ensuring critical flows are maintained during low flow periods so as to not obstruct passage of fish or negatively impact aquatic biota;
- Monitoring temperature differential of effluent and receiving water bodies to comply with local regulations respecting thermal discharge or, in the absence of such regulations, as previously noted in this document.

1.2 Occupational Health and Safety

Occupational health and safety issues during the construction and decommissioning of geothermal power generation projects are common to those of other industrial facilities and their prevention and control are discussed in the **General EHS Guidelines**.

Specific health and safety issues in geothermal power projects include the potential for exposure to:

- Geothermal gases
- Confined spaces
- Heat
- Noise

Geothermal Gases

Occupational exposure to geothermal gases, mainly hydrogen sulfide gas, may occur during non-routine release of geothermal fluids (for example, pipeline failures) and maintenance work in confined spaces such as pipelines, turbines, and condensers. The significance of the hydrogen sulfide hazard may vary depending on the location and geological formation particular to the facility.

Where there is a potential for exposure to hazardous levels of hydrogen sulfide, geothermal power facilities should consider the following management measures:

- Installation of hydrogen sulfide monitoring and warning systems. The number and location of monitors should be determined based on an assessment of plant locations prone to hydrogen sulfide emission and occupational exposure;[8]
- Development of a contingency plan for hydrogen sulfide release events, including all necessary aspects from evacuation to resumption of normal operations;
- Provision of facility emergency response teams, and workers in locations with high risk of exposure, with personal hydrogen sulfide monitors, self-contained breathing apparatus and emergency oxygen supplies, and training in their safe and effective use;
- Provision of adequate ventilation of occupied buildings to avoid accumulation of hydrogen sulfide gas;
- Development and implementation of a confined space entry program for areas designated as 'Confined Spaces' (see below);
- Providing workers with a fact sheet or other readily available information about the chemical composition of liquid and gaseous phases with an explanation of potential implications for human health and safety.

Confined Spaces

Confined space hazards in this and any other industry sector are potentially fatal. Confined space entry by workers and the potential for accidents may vary among geothermal facilities depending on design, on-site equipment, and presence of groundwater or geothermal fluids. Specific and unique areas for

[8] Alarm threshold settings for facility or personal hydrogen sulfide monitors should be set well below the recommended safety standards based on the advice of an occupational safety specialist.

confined space entry may include the turbine, condenser, and cooling water tower (during maintenance activities), monitoring equipment sheds (during sampling), and the well hole "cellar" (a subsurface depression created for drilling purposes). Geothermal power facilities should develop and implement confined space entry procedures as described in the **General EHS Guidelines**.

Heat

Occupational exposure to heat occurs during construction activities, and during operation and maintenance of pipes, wells, and related hot equipment. Non-routine exposures include potential blowout accidents during drilling as well as malfunctions of the steam containments and transport installations.

Recommended prevention and control measures to address heat exposure include:

- Reducing the time required for work in elevated temperature environments and ensuring access to drinking water;
- Shielding surfaces where workers come in close contact with hot equipment, including generating equipment, pipes etc.;
- Use of personal protective equipment (PPE) as appropriate, including insulated gloves and shoes;
- Implementing appropriate safety procedures during the exploratory drilling process.

Noise

Noise sources in geothermal facilities are mainly related to well drilling, steam flashing and venting. Other sources include equipment related to pumping facilities, turbines, and temporary pipe flushing activities. Temporary noise levels may exceed 100 dBA during certain drilling and steam venting activities. Noise abatement technology includes the use of rock mufflers, sound insulation, and barriers during drilling, in addition to silencers on equipment in the steam processing facility. Further recommendations for the management of occupational noise and vibration, such as the use of appropriate PPE, are discussed in the **General EHS Guidelines**.

1.3 Community Health and Safety

Community health and safety issues during the construction and decommissioning of geothermal power generation plants are common to those of most large industrial facilities, and are discussed in the **General EHS Guidelines**.

Community health and safety issues during the operation of geothermal power generation plants include:

- Exposure to hydrogen sulfide gas
- Infrastructure safety
- Impacts on water resources

Hydrogen Sulfide

In addition to the prevention and control of emissions and exposure to hydrogen sulfide gas described in the environmental and occupational health and safety sections above, the potential for exposures to members of the community should be carefully considered during the planning process and the necessary precautions implemented. Where the potential for community exposure is significant, examples of mitigation measures include:

- Siting of potential significant emissions sources with consideration of hydrogen sulfide gas exposure to nearby communities (considering key environmental factors such as proximity, morphology and prevailing wind directions);

- Installation of a hydrogen sulfide gas monitoring network with the number and location of monitoring stations determined through air dispersion modeling, taking into account the location of emissions sources and areas of community use and habitation;
- Continuous operation of the hydrogen sulfide gas monitoring systems to facilitate early detection and warning;
- Emergency planning involving community input to allow for effective response to monitoring system warnings.

Infrastructure Safety

Communities may be exposed to physical hazards associated with the wells and related pipeline networks. Hazards may result from contact with hot components, equipment failure, or the presence of active and abandoned well infrastructure which may generate confined space or falling hazards. Recommended management techniques to mitigate these impacts include:

- Placement of access deterrents, such as fences and warning signs, to prevent access and warn of existing hazards;
- Minimizing the length of necessary pipeline systems;
- Consideration of the feasibility of subsurface pipelines or heat shields to prevent public contact with hot geothermal pipelines;
- Managing closure of infrastructure such as pipelines and access roads, including: cleaning, disassembly, and removal of equipment; analysis of soil quality with cleanup where warranted; re-vegetation of site and blockade; and reclamation of access roads where necessary;
- Managing closure of well heads including sealing well with cement, removing the well head, and backfilling depression around the well head, as necessary.[9]

Impacts on Water Resources

The extraction, reinjection, and discharge of geothermal fluids may affect the quality and quantity of surface and groundwater resources. Examples of specific impacts include the inadvertent introduction of geothermal fluids into shallower productive aquifers during extraction and reinjection activities or a reduction in the flow of hot thermal springs due to withdrawal activities. Recommended measures to prevent and control these impacts include:

- Elaboration of a comprehensive geological and hydrogeological model including overall geological, structural and tectonic architecture, reservoir size, boundaries, geotechnical and hydraulic host rock properties;
- Completion of a hydrogeologic and water balance assessment during the project planning stage to identify hydraulic interconnections between the geothermal extraction and reinjection points and any sources of potable water or surface water features;
- Isolation of steam producing sources from shallower hydrologic formations which may be used as sources of potable water through careful site selection and properly designed and installed well casing systems;
- Avoiding negative impacts on surface water by introducing strict discharge criteria and appropriate means to bring water quality and temperature to acceptable standards.

[9] Geothermal field infrastructure decommissioning and closure may require detailed planning depending on site-specific issues.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Emissions

Minor air emissions of hydrogen sulfide, mercury vapor, and sulfur dioxide may arise as fugitive emissions from the cooling tower if the condensation process involves direct contact of steam with cooling water. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. Although geothermal energy projects do not normally generate significant point source emissions during construction and operations, hydrogen sulfide emissions, or other types of emissions, should not result in ambient concentrations above nationally established air quality standards or, in their absence, internationally recognized guidelines.[10]

Effluents

Spent geothermal fluids are typically re-injected to the host rock formation, resulting in minor effluent volumes involving reject waters. Potential contaminants in geothermal effluents will vary according to the mineralogy of the host geological formation, temperature of the geothermal water, and site-specific facility processes. If spent geothermal fluids are not re-injected, effluents should meet site-specific discharge levels for surface water as discussed in the **General EHS Guidelines**.

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[11] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[12] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[13] Indicative Occupational Exposure Limit Values

[10] Air Quality Guidelines, World Health Organization (WHO), Geneva 2000.

[11] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
[12] Available at: http://www.cdc.gov/niosh/npg/
[13] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

published by European Union member states,[14] or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)15.

Occupational Health and Safety Monitoring

The working environment should be occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[16] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[14] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/
[15] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm
[16] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

3.0 References and Additional Sources

ANZECC (Australian and New Zealand Environment Conservation Council). ANZECC. Available at http://www.deh.gov.au/about/councils/anzecc (accessed on March, 2006).

AS/NZ (Australian/New Zealand Standard on Risk Management). 1999. Australian/New Zealand Standard on Risk Management (AS/NZ 4360:1999). Auckland, NZ: AS/NZ. Available at http://www.uq.edu.au/hupp/index.html?page=30899&pid=30896 (accessed on March 2006).

Axelsson, G., and Gunnlaugsson, E. 2000. "Background: Geothermal utilization, management and monitoring." In *Long-Term Monitoring of High- and Low Enthalpy Fields under Exploitation*, World Geothermal Congress 2000 Short Courses, Japan, 3–10. Beppu, Japan.

Babok, B., Toth, A., 2003. Geothermal energy production and its environmental impacts in Hungary. International Geothermal Conference , Reykjavik, 2003., pp. 19-25.

Bay Area Air Quality Management District, Regulation 9: Inorganic Gaseous Pollutants, Rule 5 – Hydrogen Sulfide from Geothermal Power Plants. Available at http://www.baaqmd.gov/dst/regulations/index.htm#reg9 (accessed on September 11, 2006).

Brophy, Paul. 1997. "Environmental Advantages to the Utilization of Geothermal Energy." *Renewable Energy* 10:2–3, table 3.374.

Bloomfield, K., Moore, J.N., and R.M. Neilson Jr. (2003). Geothermal Energy Reduces Greenhouse Gases. Davis, CA.: Geothermal Research Council. GRC Bulletin, April 2003.

Brown, K. L. 2000. "Impacts on the physical environment." In Brown, K.L., ed., *Environmental Safety and Health Issues in Geothermal Development*, World Geothermal Congress 2000 Short Courses, Japan, 43—56. Beppu, Japan**.**

California Energy Commission. 2002. Overview of Geothermal Energy in California. Sacramento, CA. California Energy Commission. Available at http://www/energy.ca.gov/geothermal/overview (accessed on March 2006.

California Vision of Oil Gas and Geothermal Resources. 2004. Geothermal Injection Wells.: California Vision of Oil Gas and Geothermal Resources. Available at http:/www.consrv.ca.gov/DOG/geothermal/general_info/injection_wells.htm (accessed on March 2006).

Crecilius, E.A.; Robertson, D.E.; Fruchter, J.S.; and Ludwick, J.D. 1976. Chemical forms of mercury and arsenic emitted by a geothermal power plant. 10th Annual Conference on Trace Substances in Environmental Health. University of Missouri, Columbia, Missouri, United States.

Dipippo, R. 1999. Small Geothermal energy Plant, Design, Performance and Economics. Geothermal Research Council Bulletin (June).Davis, Ca.

Duffield, W.A., Sass, J.H, 2003. Geothermal Energy – Clean Power from the Earth's Heat. U.S. Geological Survey.Circular 1249. p. 43

FME (Federal Ministry for the Environment of Germany). 2005. *Geothermal Energy – Energy for the Future.* Werner Burchmann, ed. Berlin, Germany: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Available at www.bmu.de. (accessed March 2006).

Geothermal Hot Line. 1996. Subsidence and Uplift at Heber Geothermal Field. California.

Geothermal Regulatory and Reclamation Program at DOGAMI. Department of Geology and Minerals Industries. Portland, OR. Available at http://www.oregongeology.com/sub/oil/oilhome.htm (accessed on March 2006).

Geothermal Training Programme Reports. 2003. Orkustofnun, Grensásvegur 9, Number 5 IS-108. Reykjavík, Iceland.

Gutierrez-Negrin, L.C.A., and Quijano-Leon, J.L. 2004. Analysis of Seismicity in the Los Humeros, Mexico, Geothermal Field. *Geothermal Resources Council Transactions* 28: 467–72.

Hiroyuki T., H. Takagi, Y. Kiyota, K., Matsuda, Hideki Hatanaka, Kanichi Shimada, Hirofumi Inuyama, Roger Young, Larry F. Bayrante, Oliver T. Jordan, Jesus Reymundo M. Salera, and Francis Edward B. Bayon. 2000. Development and Verification of a Method to Forecast Hot Springs Interference due to Geothermal Power Exploitation. Proceedings World Geothermal Congress 2000. Kyushu - Tohoku, Japan, May 28–June 10, 2000.

International Geothermal Association. 2001. Report of the IGA to the UN Commission on Sustainable Development, Session 9 (CSD-9), New York, April 2001.

International Energy Agency. 2003. Appendices to Report on Benign Energy: The Environmental Implications of Renewables. Appendix G Geothermal Paris, France: International Energy Agency. Available at http://www.iea.org/pubs/studies/files/benign/pubs/append3g.pdf (accessed on March 2003).

Kagel. A, D. Bates, and K. Gawell. 2005. *Clear the Air: Air Emissions from Geothermal Electric Power Facilities Compared to Fossil-Fuel Power Plants in the United States.* Washington, DC: Geothermal Energy Association, GRC Bulletin, May/June.

Kestin, J. (Editor). Source book on the production of electricity from Geothermal Energy. US Department of Energy. Division of Geothermal Energy. Washington, D.C.

Krzan, Zbigniew. 1995. "Environmental Protection of the Tatra, Pieniny and Gorge Mountains by the Use of Geothermal Energy." *WGC* 4: 2799–800.

Lienau, P.J., and Lunis, B.C. (editors), 1991. Geothermal direct use engineering and design guidebook. Geoheat Center, Oregon Institute of Technology.

Lunis, B., and Breckenridge, R. 1991. "Environmental considerations." In Lienau, P.J. and Lunis, B.C., eds., *Geothermal Direct Use, Engineering and Design Guidebook*, 437–45. Klamath Falls, Oregon: Geo-Heat Center.

Philippines DOE (Department of Energy). 2002. Guidelines for Geothermal Operations in the Philippines. Bureau Circular No. 83-01-02 .Manila. DOE. Available at www.doe.gov.ph/peer2005 (accessed on March 2003.

Reed, Marshall J., and J. Renner. 1995. "Environmental Compatibility of Geothermal Energy." In F.S. Sterret, eds., *Alternative Fuels and the Environment.* Boca Raton: CRC Press.

Takashashi, K, M. Kuragaki, 2000. Yanaizu-Nishiyama geothermal power station H2S Abatement. Proceedings of World Geothermal Congress, Beppu, Japan, 2000. pp. 719-724

Timperly, M.H., and L.F. Hill, (1997). Discharge of mercury from the Wairakei geothermal power station to the Waikato River, New Zealand. New Zealand Journal of Marine and Freshwater Research, 1997, Vol. 31: 327-336

UNEP (United Nations Environmental Programme). 2005. Guidelines for Geothermal Energy Systems (Release 1.0) Environmental Due Diligences of Renewable Energy Projects, United Nations Environmental Programme. UNEP. Available at www.energy-base.org/fileadmin/ media/sefi/docs/edd_geothermal.pdf (accessed on November 5, 2005).

U.S. DOE (U.S. Department of Energy), 2000. Revised Geothermal Safety and health rules and regulations. Department Circular 2000-02-001. Washington DC.

US DOE (U.S. Department of Energy). 2001. Energy and Geosciences Institute at University of Utah. Geothermal Energy: Clean Sustainable Energy for the Benefit of Humanity and the Environment (Brochure).. Washington, DC: US DOE. Available at http://www.geo-energy.org/RedBrochure.pdf (accessed on October 2004).

US DOE (U.S. Department of Energy), Energy Efficiency and Renewable Energy (EERE). 2004. Geothermal Technologies Program. Geothermal energy Plants.. Washington, DC: US DOE/EERE. Available at http://www,eere.gov/geothermal/powerplants.html (accessed on December 6, 2004).

US DOE (U.S. Department of Energy), Geothermal Technologies Program. 2004. Geopowering the West: Hawaii Facts Sheet. December 21, 2004. Washington, DC: US DOE. Available at http://www.eere.energy.gov/geothermal/gpw_hawaii.html (accessed on March 2006).

U.S. DOE (U.S. Department of Energy), NERL (National Renewable Energy Laboratory). 2001. Geothermal Energy: Heat from the Earth (Publication No. DOE/GO – 102001-1432). Washington, DC: US DOE/NERL. Available at http://www.nrel.gov/dos/fy02osti/29214/pdf (accessed on December 6, 2004).

Utah Water Quality Act. 2004. The Utah Water Quality Act and Title R317 - Environmental Quality and Water Quality, 2004. State of Utah.

Weres, O. 1984. Environmental Protection and the Chemistry of Geothermal Fluids. Berkley, CA.: Lawrence Berkeley Laboratory, LBL 14403.

World Bank Group. 2002. Geothermal Energy. Washington, DC: World Bank Group. Available at http://www.worldbank.org/html/fpd/energy/geothermal/ (accessed on December 6, 2004).

World Health Organization (WHO), Air Quality Guidelines, Second Edition, Geneva, 2000. Available at http://www.euro.who.int/air/activities/20050223_3 (accessed on September 11, 2006).

World Energy Council website (June 2006): http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/3_1_17.asp

Wright, P.M. 1998. The Sustainability of Production from Geothermal Resources. Bulletin. Geo-Heat Center 19(2): 9–12.

Annex A: General Description of Industry Activities

Geothermal power generation involves harnessing high-temperature, underground reservoirs of geothermal waters or steam, and converting the thermal energy to electricity. Geothermal power generation plants are typically located adjacent to sources of thermal energy to reduce heat losses from transportation. Longer distances for power transmission and distribution can be accommodated by appropriately sized power lines. Geothermal power plants typically require 0.5 to 3.5 hectares of land per megawatt (MW). Integrated geothermal developments provide power generation and may use residual heat from the rejected geothermal fluid in a variety of potential downstream industries, such as greenhouses, aquaculture, space heating, food / fruit processing, recreational hotel / spa use, among others.[17]

The basic components of geothermal power generation facilities include wells to access steam and superheated groundwater, steam turbines, generators, condensers, cooling towers, reinjection pumps, and electrical grid interconnection equipment.

Geothermal energy projects involves three major stages, including exploration and reservoir evaluation, production field development, and power plant construction.

Exploration and reservoir evaluation activities include geological, geophysical, and drilling surveys for exploratory drilling and reservoir testing.

Production field development involves drilling steam or hot water production wells and re-injection wells and processing of the reservoir output for use in the power plant. Drilling will continue throughout the life of the project, as production and injection wells need to be periodically updated to support power generation requirements.

Power plant construction activities include construction of the power plant facility and associated infrastructure, including cooling towers, pipelines, and facilities for treatment and reinjection of wastewaters and gases. Other activities include establishment of settling ponds to support drilling and well testing, and construction of access roads, storage yards, and maintenance facilities.

Operational activities include routine operation and maintenance of the geothermal power plant, well field monitoring and maintenance, periodically drilling of production and injection wells, geothermal fluid processing and pipeline maintenance.

Superheated geothermal fluids typically contain a number of dissolved metals and gases. Wastewater effluents and gases are typically re-injected into the reservoir or its periphery to minimize the potential for groundwater contamination. Construction of settling / cooling ponds with lagoon covers to capture and scrub gases is sometimes necessary for circumstances in which the reinjection of wastewater fluids and gases is not possible.

Depending on the design of the facility, cooling towers may use geothermal fluids or borrow from surface water sources for circulation. Hazardous solid waste may be generated from the sulfur precipitates within the condensate and should be removed and properly stored on site before disposal.

There are two major types of geothermal resources: dry steam and hot water[18]. In dry steam resources, the output of the producing wells is a dry steam which can be used directly to run the turbine-generators while in hot water resources, the well discharge is high-temperature (>180 °C) water. For water resources under 180°C, power generation is possible using a

[17] Lienau and Lunis (1991)

[18] Duffield and Sass (2003)

binary cycle system involving the use of a secondary fluid, as explained below.

Geothermal power generation projects generally involve one of the following processes, or combination of processes:

- **Geothermal flash steam:** Steam is separated from the hot water resource and used for power when the temperature of the resource is above 180ºC, which allows extraction of some high-pressure steam through 'flashing' in steam separators to run the turbine generator. Single flashing, dual flashing, and occasionally triple flashing are common technologies. The steam portion is used in turbines and the remaining hot water is rejected or re-injected to the reservoir.
- **Geothermal binary process:** When the resource temperature is below 180°C, a secondary cycle using a low boiling point fluid, such as isobutene, isopentane or an ammonia-water mixture, is used to interface between the heat source (geothermal fluids) and the turbine.
- **Combined geothermal flash/binary:** Both flashing and binary processes are used to increase efficiency.
- **Geothermal dry steam processes:** High-pressure dry steam discharged from the production wells is used directly in the turbines to generate electricity. Dry steam resources are highly valuable but relatively rare.