Background Notes
EcoLogo[TM] Program Standard Review (Round 1)

CCD-003 Electricity-Renewable Low-Impact

(D) GEOTHERMAL-POWERED ELECTRICITY

Table of Contents

May 14, 2009

1 Introduction

Geothermal-powered electricity is not currently included in the EcoLogo™ renewable low-impact electricity standard (CCD-003) and therefore, no geothermal plants have yet been third-party certified by the EcoLogo™ Program. However, based on a preliminary review of life cycle information, geothermal electricity products, if properly built, could offer considerable environmental benefits and meet strict requirements for *inter alia* a reduction in noxious air emissions, water emissions, and hazardous waste.

During a preliminary research period, the EcoLogo™ Program engaged with stakeholders to narrow down the scope of environmental criteria needing to be added to the standard. As such, the EcoLogo™ Program was able to narrow down its criteria scope. This scope will be presented in this document. Moreover, the EcoLogo™ Program will propose environmental leadership criteria for further stakeholder review, as well as outline unresolved issues for further consideration by stakeholders.

2 New Criteria Statements to the Current Active Standard

Following preliminary research and a discussion with stakeholders, the EcoLogo™ Program will address the following environmental impact categories and related stressors by proposing to add new criteria statements to the current active standard. Each proposed criteria statement is followed by a rationale explaining why we are proposing the addition to the standard. Only those topics that were discussed with stakeholder will be presented below.

2.1 Impacts due to Re-Injection

[Addition]:

See individual pollutant thresholds proposed elsewhere in this standard.

<u>Rationale:</u>

According to Bargali et al. (1997), "the old geothermal power plants had an environmental impact (per unit of power produced) that was higher than, or comparable to, that of coal-burning power plants (Axtmann 1975). In the last decade, this impact has been sharply reduced in new plants by re-injection of condensable spent fluids into the ground." However, in the U.S., 20% of 70 geothermal fields investigated show environmental damages due to re-injection, such as cooling down of the reservoir fluids by time, contamination of aquifers, ground heaving, and induced seismic activity (Sanyal, Granados, & Menzies, 1995). According to Dogdu & Bayari (2004):

> *The cessation of thermal water production or re-injection of thermal water to prevent pollution in stream water may also lead to elevated hydraulic pressure in thermal aquifer, which in turn may increase the upward leakage to the freshwater aquifer. The release of geothermal fluids in surface environment will apparently lead to damages whose cost may far exceed the benefits gained from the heat energy. For this reason, [contaminants] brought to surface for any purpose should be removed from the surface environment by using the most economically feasible way. Chemical treatment methods may be employed to remove compounds of Na, Li, K, and As etc. Such an approach will not only remove the contaminants from the surface environment, but*

would also result in additional economic gains. Another alternative solution to removal of Afjet thermal return water (ATRW) seems to be sequential precipitation of minerals via evaporation as applied in saltpans.

Because of the risk of water contamination, the Defenders of Wildlife (2008) believe that it is critical that waste waters be re-injected in a way that ensures groundwater aquifers are not polluted, including ensuring well casings do not have leaks. According to the Geothermal Energy Association (GEA; 2007), it is common practice that geothermal fluids used for electricity are injected back into geothermal reservoirs using wells with thick casing to prevent cross-contamination of brines with groundwater systems. Besides being a potential risk to groundwater, according to Majer (2006), water injection seems to be one of the most common causes of induced seismicity. The largest occurrence of seismic activity believed to have been caused by re-injection had a magnitude of 5.3. At this site, 30 million liters/month were being re-injected over 4 years, thereby causing too much pressure. A level 5 seismic activity can cause major damage to structures. Pasqualetti (1979) points out that the withdrawal of condensate could also lead to seismicity. However, despite risks of seismicity and groundwater contamination, some argue that re-injecting spent geothermal fluids back into reservoirs to sustain resources, helps prevent another problem: land subsidence. This, however seems to be a rare problem. In fact, according to the Defenders of Wildlife (2008), the problem of land subsidence has so far only been detected at one site located in New Zealand. According to Bargali et al. (1997), land subsidence may also occur especially if fluid withdrawal exceeds the natural inflow.

To ensure that the above problems caused by re-injection are mitigated, the EcoLogo™ Program proposes that thresholds of the high risk pollutants should be identified and included in the new renewable low-impact electricity standard. These pollutant thresholds are addressed individually elsewhere below in this document.

2.2 Trace Air and Water Emissions

2.2.1 Boron Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (a) boron emissions do not surpass 1 ppm in geothermal well waters

Rationale:

According to Koc (2007), typical boron concentrations in North American waters are below 0.1 ppm, with about 90% at or below 0.4 ppm (WHO, 1998a). According to Ellis (1978), common compositions of geothermal well waters are of 1-1000 (often 20-50) ppm and of 0.01-1 ppm in steam condensates. Boron is an essential element for plant growth. Boron however, is only needed in relatively small amounts, and if present in amounts appreciably greater than needed, it may become toxic. For plants, 1 to 2 ppm of boron may be toxic. While crops may suffer toxicity, the concentrations found in crops (typically 12 ppm) (Atwell, Kriedemann, & Turnbull, 1999) generally do not pose a threat to human health and no recommended dietary intake for humans has been set. According to Ellis (1978), while the presence of boron in geothermal effluents may threaten irrigation waters, it is not a critical element from a health viewpoint. Normal diets include 10-20 mg of boron per day and concentrations of up to 20 ppm are permitted in drinking water (Waggott, 1969). In general, treatment methods, such as reverse osmosis and ion exchange could be used to remove boron as well as other trace elements. According to the GEA (2007), new geothermal plants are now required to install high efficiency drift eliminators for particulate control, regardless of boron content in the water, which will reduce boron emissions. Boron salt compounds may be emitted in cooling tower drift, but boron emissions are generally not regulated. The EcoLogo™ Program therefore proposes to mandate that the level of boron in geothermal well waters not exceed the potential toxic level for plants of 1ppm.

2.2.2 Ammonia Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

    (b) ammonia emissions do not surpass 1 ppm in geothermal well waters;

Rationale:

In Ellis (1978), it is mentioned that common concentrations of ammonia in geothermal plants is often 1-10 ppm in well waters and 1-50 ppm in steam condensates (Ellis and Mahon, 1977; Reed and Campbell, 1975). According to Pasqualetti (1979), the most harmful ingredients for surface discharges of geothermal plants include ammonia at about 100-200 ppm. He mentions that the ammonia is harmful to fish. According to Great Lakes Bio Systems (2009), "For freshwater species the range of 0.53 to 22.8 mg/L (ppm) is generally regarded as toxic, but problems will begin to occur from amounts greater than 0.1 mg/L (ppm). At over 0.1 mg/L (ppm) skin, eye, gill, and internal organ damage can occur." The EcoLogo™ Program proposes that the ammonia concentration in geothermal well waters should be the lowest possible for geothermal plants: 1 ppm to reduce the possibility of contaminating waters where fish may be.

2.2.3 Lead Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

    (c) lead emissions do not surpass 0.01 ppm in geothermal well waters;

Rationale:

According to Ellis (1978), it is seldom that concentrations of lead in the dilute neutral-pH chloride waters tapped in volcanic geothermal areas exceed those that were permitted in drinking waters of 0.05 ppm. However, concentrations are higher in the very saline thermal waters of sedimentary systems such as in the Cheleken Peninsula (Lebedev, 1972), the Salton Sea geothermal area (White, 1968) or in very acid geothermal areas such as Matsao, Taiwan (Ellis and Mahon, 1977). Contamination problems from lead should be anticipated with geothermal waters of salinity over about 10,000 ppm. Health Canada (2009a)'s guideline for lead currently states that "The maximum acceptable concentration (MAC) for lead in drinking water is 0.010mg/L (0.01 ppm)." Therefore, the EcoLogo™ Program proposes this threshold level in the draft standard.

2.2.4 Cadmium Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (d) cadmium emissions do not surpass 0.005 ppm in geothermal well waters;

Rationale:

According to Ellis (1978), it is seldom that concentrations of cadmium in the dilute neutral-pH chloride waters tapped in volcanic geothermal areas exceed those that were permitted in drinking waters of 0.01 ppm. However, concentrations are higher in the very saline thermal waters of sedimentary systems such as in the Cheleken Peninsula (Lebedev, 1972), and the Salton Sea geothermal area (White, 1968). Contamination problems from lead should be anticipated with geothermal waters of salinity over about 10,000 ppm. According to Health Canada (2008b), "A maximum acceptable concentration of 0.005 mg/L (0.005ppm) for cadmium in drinking water has been established on the basis of health considerations." Therefore, the EcoLogo™ Program proposes this threshold level in the draft standard.

2.2.5 Radon Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (e) radon emissions do not surpass 300 pCi/L in geothermal well waters;

Rationale:

According to Birkle & Merkel (2000), Radon-222 represents a potential health risk for humans. The particular hazard from radon involves the inhalation and deposition of the short-lived daughters. According to Pasqualetti (1978), the 222Rn does not deposit on lung tissue when inhaled, but is merely exhaled. The short-lived daughters, however, are usually deposited, and these can cause cancer. Maximum measurements of radon from the steam at a well geyser of 8.3 picocuries/liter have been recorded (Pasqualetti, 1978). The EPA's maximum contaminant level for drinking water, on the other hand, is of 300 pCi/L (1999). With a transfer coefficient of $1*10^{-4}$ from water to air, as mentioned by the National Research Council Committee on Risk Assessment of Exposure to Radon in Drinking Water (1999), 300 pCi/L could translate to a concentration of approximately 0.03 pCi/L in the air. This means that geothermal well waters could exceed the EPA's proposed water rule for radon. Because of this, the EcoLogo™ Program proposes to set a threshold following the EPA's rule for radon in its draft standard.

2.2.6 Arsenic Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

(f) arsenic emissions do not surpass 0.010 ppm in geothermal well waters;

Rationale:

In general, geothermal plants are not considered to be high arsenic emitters even though arsenic is common to volcanic systems. When arsenic is present in a geothermal system, it typically ends up in the solid form in the sludge and scales associated with production, and hydrogen sulfate abatement. Arsenic emission levels have been well documented over the years through two emissions inventories in California: the Air Toxic Hot Spots Program and The Geysers Air Monitoring Program (GAMP), both of which have shown limited arsenic emissions. Results of these programs have shown arsenic emissions levels from geothermal power plant to be very small, if they are even detectable. A study of The Geysers showed that arsenic emissions were not of significant concern: the average level at The Geysers around 1.6 ng/m^3 [1.6 10^{-6} ppb], was found to be very close to the statewide average of 1.5 ng/m^3 [1.6*10^{-6}ppb]. Also, according to another study of arsenic in geothermal steam condensate by Reed and Campbell (1975), a range of 0.3-18 ppb was found at The Geysers steam with an average of 5 ppb which presents no health hazard (Ellis, 1978, p.182). Although arsenic in the U.S. does not seem to pose a risk, in El Salvador, arsenic concentrations of 11.3 ppm were found at several wells of a power plant (Pasqualetti, 1979). Currently, the Canadian Guidelines for Canadian Drinking Water Quality for arsenic is of 0.010mg/L (Health Canada, 2008c). Although generally, geothermal power plant concentrations of arsenic in well waters do not seem to pose a significant risk, it seems that in certain rare circumstances, the concentrations could exceed the Canadian water guideline of 0.010 ppm. Because of this, the EcoLogo™ proposes to include this threshold within CCD-003.

2.2.7 Chloride Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

(g) chloride emissions do not surpass 250 mg/L ppm in geothermal well waters;

Rationale:

The Defenders of Wildlife (2008) and the IFC (2007) both mention that geothermal plants could emit chloride emissions at levels that may pose environmental risks. Ellis (1978) mentions that well waters concentrations of NaCl range from 500-200,000ppm in geothermal plants and 0-1 ppm in steam condensates. Currently, the Canadian aesthetic objective for Canadian Drinking Water Quality is of 250mg/L [250 ppm] (Health Canada, 2008d). Therefore, the EcoLogo™ Program proposes this threshold level in the draft standard.

2.2.8 Nickel Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

(h) nickel emissions do not surpass 0.07 ppm in geothermal well waters;

Rationale:

The Defenders of Wildlife (2008) and the IFC (2007) both mention that geothermal plants could emit nickel emissions at levels that may pose environmental risks. The World Health Organization (2005) currently gives a drinking water guideline value of 0.07 mg/L ppm. Therefore, the EcoLogo™ Program proposes this threshold level in the draft standard.

2.2.9 Vanadium Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (i) vanadium emissions do not surpass 1 $\mu g/m^3$ (averaging time of 24 hours) in geothermal steam condensate;

Rationale:

According to CERM3 (2002), scrubbers reduce air emissions but a low-density sludge high in vanadium is produced. Vanadium can be toxic in high concentrations, but it can also be recovered for market from this source. According to the World Health Organization (2000), "It is believed that below 1 $\mu g/m^3$ (averaging time of 24 hours) environmental exposure to vanadium is not likely to have adverse effects on health. Therefore, the EcoLogo™ Program proposes this threshold level in the draft standard.

2.2.10 Fluoride Emissions

[Addition]:

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (j) fluoride emissions do not surpass 1.5 ppm in geothermal well waters;

Rationale:

According to Ellis (1978), concentrations of 1 to 20 ppm are found in geothermal well waters. According to Health Canada (2008), "Fluoride is one of the many chemicals for which guidelines have been set. The maximum acceptable concentration of fluoride in drinking water is 1.5 mg/L [ppm], a level at which Health Canada (2008e) believes there is no undue health risks." Therefore, the EcoLogo™ Program proposes this threshold level in the draft standard.

2.3 Land Use and its Impacts on Land Ecosystems

Rationale:

See *General Considerations* Background Notes presented elsewhere for the review of CCD-003.

2.4 Impacts of Drilling Fluids and Cuttings

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (k) The IFC (2007) Environmental, Health, and Safety Guidelines for Geothermal Power Generation section *Drilling Fluids and Cuttings* is followed

Rationale:

According to the IFC (2007):

> *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.*

The EcoLogo™ Program thinks appropriate the above management of drilling fluids and cuttings methods.

2.5 Releases due to Blowouts

8. To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

   (l)The IFC (2007) Environmental, Health, and Safety Guidelines for Geothermal Power Generation section *Well Blowouts and Pipeline Failures* is followed.

Rationale:

According to the IFC (2007):

> *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*

3 Considerations Withdrawn from Review

Following preliminary research and a discussion with stakeholders, the EcoLogo™ Program has withdrawn the following environmental considerations from this review. Below, we provide a rationale explaining why we have decided not to address these considerations further during this review. Only those topics that were discussed with stakeholder will be presented below.

3.1 Noise

Rationale:

Although The EcoLogo™ Program recognizes noise as a potential damaging issue related to wind-powered electricity, we think that noise issues, if relevant, would be adequately addressed by the current 4 a), 4b) an 4c) sections of the active standard. Therefore, the EcoLogo™ Program does not think it necessary to further consider this issue during this review.

3.2 Hazardous Waste Disposal

Rationale:

According to the IFC (2007), 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. Moreover, as mentioned previously, isobutane is used in binary geothermal cycle plants. According to Butterfield (n.d.), another fluid used in this type of plant is isopentane. This fluid, according to the International Labor Organization (2008), is harmful to aquatic organisms. Also, both isobutene and isopentane are extremely flammable substances. Therefore, it is important that these substances be handled carefully at all stages of the life of geothermal plants.

The EcoLogo™ Program already addresses hazardous waste in CCD-003. Indeed, the current *General Requirements* state that:

> *To meet the requirements of this Standard, the electricity - renewable low-impact must:*
>
> > *(b) be generated in such a manner that all steps of the process, including the disposal of waste products arising therefrom, will meet the requirements of all applicable governmental acts, by laws, and regulations including, for facilities located in Canada, the Fisheries Act and the Canadian Environmental Protection Act, 1999, (CEPA, 1999).*

The EcoLogo™ Program therefore thinks that the current standard adequately addresses hazardous waste from geothermal electricity production and does not think it necessary to further consider this issue during this review.

3.3 Renewable and Low-Impact Nature of Geothermal-Powered Electricity

Rationale:

According to CCD-003, "renewable" means replenished through natural processes or through sustainable management practices so that a resource is not depleted at current levels of consumption. The EcoLogo™ Program thinks that geothermal electricity in general can be considered renewable because the natural processes generally do not exhaust themselves. When production cannot be maintained at the natural discharge rate, re-injection can be done as long at it is done in a sustainable manner. This issue is already addressed in the section on the *Impacts due to Re-injection* and therefore we do not consider it necessary to elaborate further on this question here.

3.4 Major Air Emissions

3.4.1 Greenhouse Gas Emissions

Rationale:

See *General Considerations* Background Notes presented elsewhere for the review of CCD-003.

3.4.2 H_2S Emissions

Rationale:

Some plant technologies can be used to convert H_2S gases into sulfur. Sulfur can then potentially be recycled to use as a feedstock for sulfuric acid. However, this is not necessary for all plants since some emit very small quantities of H_2S comparatively to others. According to Ellis (1978), H_2S emissions of geothermal plants can approach those of coal-fired power plants in extreme cases. Casualties have also occurred in isolated areas of unusually high concentrations of H_2S, such as well-pits and thermal baths (Ellis, 1978). The oxidation of H_2S to SO_2 and its subsequent reaction to sulfate ions within the atmosphere produces aerosols representing a major component of acid rain (Birkle & Merkel, 2000). The EcoLogo™ Program proposes to address H_2S emissions indirectly by addressing SOx emissions.

3.5 Trace Air and Water Emissions

3.5.1 Mercury Emissions

Rationale:

According to GEA (2007), although mercury is not present in every geothermal resource, where it is present, mercury abatement equipment typically reduces emissions by 90 percent or more. The comparatively highest mercury emitters, two facilities at The Geysers in California, release mercury at levels that do not trigger any health risk analyses under strict California regulations. According to Health Canada (2008f), mercury is a toxic element and serves no beneficial physiological function in man. Also, they've established a maximum acceptable concentration of *0.001 mg/L* [0.001ppm] in drinking water. According to Ellis (1978), Hg well waters concentrations from geothermal plants range from 0.0001-0.001 ppm. Since this is below the Health Canada threshold, the EcoLogo™ Program will not consider mercury emissions further during this review.

3.5.2 Criteria Air Emissions (NOx and SOx Emissions)

Rationale:

See *General Considerations* Background Notes presented elsewhere for the review of CCD-003.

4 Unresolved Issues

Following preliminary research and a discussion with stakeholders, the EcoLogo™ Program has not been capable of resolving certain issues. Indeed, no clear direction could be found indicating how EcoLogo™ should address these issues, although in certain cases, several proposals were brought forward. The goal of the EcoLogo™ Program is to determine whether these issues can be resolved and what criteria statement could be included in the standard. Only those topics that were discussed with stakeholder will be presented below.

4.1 Water Use and its Impacts on Water Ecosystems

[Proposal]:

To meet the requirements of this standard, geothermal-powered electricity must be generated in such a manner that:

X L/MWh of water is consumed

Rationale:

As previously mentioned, Brophy (1997), has argued that by injecting fluids back into the geothermal system, reservoir pressures and groundwater flow can be maintained as close as possible to pre-development levels. In some cases, like at the Geysers, in California, 11 million gallons of recycled water is pumped each day. Before the Geysers Recharge Project, this filtered UV treated tertiary recycled water, which meets or exceeds the highest level recognized in California water recycling regulations, would have been discharged into the Russian River (City of Santa Rosa, 2004-2007). As shown in the section on seismicity above, the amount of water could induce seismic activity. The amount of water or freshwater use of average geothermal plants is of 5 gallons (18L) of freshwater/MWh or 0 gallons/MWh for binary air-cooled plants (GEA, 2007b). To put this into perspective, water consumption for other types of electricity sources not consumed, not including water withdrawn, range between 0 and 4180 L/MWh according to the Ontario Power Authority & SENES Consultants Limited. (2005). Also in terms of water use, according to the Defenders of Wildlife (2008), there is also the potential for conflict with other water users, for water resources where water is not plentiful, that need to be addressed. According to them, a large amount of water is also needed for cooling and other purposes in most geothermal plants. Heated waters should not be disposed of into naturally cooler streams due to the negative impacts on aquatic ecosystems, and withdrawals of cooling water should not be allowed to de-water streams or otherwise disrupt the ecological functions in aquatic environments. Geothermal plants can use cooling towers or air-cooled condensers to reject waste heat into the atmosphere instead of waterways unlike most nuclear and fossil fuels power plants. The IFC (2007) also recommends that geothermal plant operators assess the hydrological records for short and long-term variability of streams serving as source water, to ensure critical flows are maintained during low flow periods so as to not obstruct passage of fish, or negatively impact aquatic biota.

At this time, the EcoLogo™ Program does not know if and how a water use threshold needs to be set for geothermal plants in North America. We are therefore seeking further input from stakeholders to help answer the question below.

<u>Question:</u>

What should be the value of X and why? Please substantiate your answer with data.

4.2 Hydrogen Emissions

The general risks associated to hydrogen emissions include: explosivity, flammability, and high concentrations in the air. This can cause a deficiency of oxygen with the risk of unconsciousness (ISOC Technology. (n.d.). At this time, the EcoLogo™ Program does not know if and how a hydrogen threshold needs to be set for geothermal plants in North America.

<u>Question:</u>

Do you think that the EcoLogo™ Program should identify a maximum threshold level of hydrogen emissions for geothermal plants? If so, why and what do you think this threshold level should be? If not, why not?

5 References

Bargagli, R., Cateni, D., Nelli, S., Olmastroni, S., & Zagarese, B. (1997). Environmental Impact of Trace Element Emissions from Geothermal Power Plants. *Archives of Environmental Contamination and Toxicology*, *33*, 172-181.

Birkle, P., & Merkel, B. (2000). Environmental impact by spill of geothermal fluids at the geothermal field of Los Azufres Mochacán, Mexico. *Water, Air, and Soil Pollution*, *124*, 371–410.

Brophy, P. (1997). Environmental Advantages to the Utilization of Geothermal Energy. *Renewable Energy*, *10* (issue 2/3), 367-377.

Butterfield, L. (n.d.). *Geothermal Energy*. Retrieved June 13, 2008, from http://www.eere.energy.gov/education/lessonplans/pdfs/geothermal_energy.pdf

City of Santa Rosa. (2004-2007). *Facts & Stats*. Retrieved June 6, 2008, from http://ci.santa-rosa.ca.us/DEPARTMENTS/UTILITIES/IRWP/GEYSERS/Pages/FactStat.aspx

Defenders of Wildlife. (2008). *Detailed Recommendations for Geothermal Energy*. Retrieved June 6, 2008, from http://www.defenders.org/programs_and_policy/policy_and_legislation/energy/renewable_energy/geothermal_energy/detailed_recommendations.php

Dogdu, M. S., & Bayari, C. S. (2004). Environmental impact f geothermal fluids on surface water, groundwater and streambed sediments in the Akarcay Basin, Turkey. *Environmental Geology*, *47*, 325-340.

Ellis, A. J. (1978). Geothermal fluid chemistry and human health. *Geothermics*, *6*, 175-182.

Geothermal Energy Association. (2007). *A Guide to Geothermal Energy and the Environment*. Retrieved May 1, 2008, from http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf

Koc, C. (2007). Effects on Environment and Agriculture of Geothermal Wastewater and Boron Pollution in Great Menderes Basin. *Environmental Monitoring and Assessment, 125*, 377–388.

Health Canada. (2009a). *Lead*. Retrieved May 7, 2009, from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/lead-plomb/i-eng.php#a1

Health Canada. (2008b). *Cadmium*. Retrieved May 7, 2009, from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/cadmium/index-eng.php

Health Canada. (2008c). *Arsenic*. Retrieved May 7, 2009, from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/arsenic/guideline-recommandation-eng.php

Health Canada (2008d). *Chloride*. Retrieved April 7, 2009 from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/chloride-chlorure/index-eng.php

Health Canada. (2008e). *Fluoride and Human Health*. Retrieved April 8, 2009, from http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/fluor-eng.php

Health Canada.(2009f). *Mercury*. Retrieved April 7, 2009, from http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/mercury-mercure/i-eng.php#a1

International Finance Corporation. (2007). *Environmental, Health, and Safety Guidelines for Geothermal Power Generation*. Retrieved June 6, 2008, from http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_GeothermalPowerGen/$FILE/Final+-+Geothermal+Power+Generation.pdf

ISOC Technology. (n.d.) *Material Safety Data Sheet: Hydrogen*. Retrieved October 24, 2008, from http://www.isocinfo.com/DocumentRoot/13/Hydrogen.pdf

Majer, E. L. (2006). *Induced seismicity associated with enhanced geothermal system*. Retrieved June 6, 2008, from http://repositories.cdlib.org/lbnl/LBNL-61681/

National Research Council Committee on Risk Assessment of Exposure to Radon in Drinking Water. (1999). *Risk Assessment of Radon in Drinking Water*. Retrieved April 7, 2009, from http://www.nap.edu/openbook.php?record_id=6287&page=R1

Ontario Power Authority & SENES Consultants Limited. (2005). *METHODS TO ASSESS THE IMPACTS ON THE NATURAL ENVIRONMENT OF GENERATION OPTIONS*. Retrieved September 3, 2008, from http://www.energy.gov.on.ca/opareport/Part%204%20-%20Consulting%20Reports/Part%204.4%20SENES%20Final%20Report%20to%20OPA.pdf

Pasqualetti, M. J. (1979). Geothermal Energy and the Environment: the Global Experience. *Energy*, 5, 11-165.

Sanyal, S. K., Granados, E.E., & Menzies, A. J. (1995). Injection- Related Problems Encountered in Geothermal Projects and their Mitigation: the United States Experience. *Conference Proceedings from World Geothermal Congress '95*. Florence, Italy.

U.S. Environmental Protection Agency. (1999). *National Primary Drinking Water Regulations; Radon-222*. Retrieved May 7, 2009, from http://www.epa.gov/fedrgstr/EPA-WATER/1999/November/Day-02/w27741a.htm

World Health Organization.(2000). *Air Quality Guidelines for Europe*. Retrieved April 8, 2009, from http://books.google.com/books?id=WVg8CYswPu4C&pg=PA170&lpg=PA170&dq=World+Health+Organization+vanadium&source=bl&ots=zKDzo_pkey&sig=1f7TrB9QwwenYS4TQ5dgXpPbI2U&hl=en&ei=B9bbSaKilaXuMtPQ2M0I&sa=X&oi=book_result&ct=result&resnum=1#PPR1,M1

World Health Organization. (2005). Chemical Hazards in Drinking Water-Nickel. Retrieved April 7, 2009, from http://www.who.int/water_sanitation_health/dwq/chemicals/nickel/en/