Summary of Potential Effects of 345-kV Power-Line Electric and Magnetic Fields (EMFs) on Honeybee Hives and Honeybee Behavior

Prepared for:

CapX2020

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1 Overview of Project-Specific ELF-EMF and Honeybees

The interactions between honeybees and power-line, extremely low frequency ("ELF") electric and magnetic fields ("EMFs"), similar to those projected for the CapX2020 transmission lines, have been examined in scientific studies. In those studies, little has been found in the way of adverse effects, and nothing has been found regarding adverse impacts on honeybees of EMFs at levels projected for the CapX2020 transmission lines. The types of ELF-EMFs projected for the CapX2020 transmission projects are encountered frequently near existing transmission-line corridors. Additionally, literature on beekeeping appears not to identify any problems specific to overhead transmission lines at 345-kV and below. Some websites on the Internet suggest that effects such as honeybee "Colony Collapse Disorder" are related to magnetic fields, but those Internet sources focus on the radiofrequency ("RF"), cell-phone portion of the electromagnetic spectrum and not on ELF-EMFs. [1]

2 Studies of Honeybees in High-Level Power-Line Electric-Fields

Research studies have found behavioral changes in bees when subjected to elevated ELF electric fields, but at levels greater than those projected for the CapX2020 transmission lines. Although typical ELF electric fields do not affect organism cellular and molecular function, external electric fields of a sufficiently elevated intensity can cause physical effects in whole organisms, because of force on hairs and hair-like structures, and potentially *via* small electric shocks. Honeybee hives exposed to ELF electric fields higher than those projected for the CapX2020 project can exhibit bee behavioral changes such as increased motor activity, redistribution of honeycomb material (propolis), lower foraging rates, and decreased winter survival. These effects, however, are documented only at electric field intensities above 4.0 kV/m (Greenberg *et al*., 1981), and the maximum electric field, directly under the proposed CapX2020 lines at the point of maximum sag is about 3.7 kV/m. Locations away from this point, either laterally toward the edge of the right-of-way, or along the lines toward the support structures, would have lower electric fields.

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1 See: http://broschuerenreihe.net/britannien-uk/brochure/bees-birds-and-mankind/index.html There is no evidence that power-line, ELF-EMF is a factor in honeybee CCD, which became an increasing problem in only in 2006 and later. Instead, it appears that the varroa mite, which was accidentally introduced to the United States in 1986, is a carrier of a picorna-like virus, which is likely leading to ribosome breakdown in bees, and which is likely the factor contributing to some bee colony decline in US honeybee hives.

Some research experiments have exposed honeybees for two months to 60-Hz electric fields up to as high as 100 kV/m. If exposure occurs under dry, moisture-free conditions, within nonconductive hives (tunnels), there is no deleterious effect on colony behavior, even at 100 kV/m. However, if the bees were exposed to electric fields in the range 50 to 100 kV/m under wet conditions (*i.e.* condensation or rain), then some deleterious effects, such as increased mortality, disturbed hive construction, and possible impairment of colony growth were observed. The investigators concluded that the effect of high-level ELF electric fields on disturbing bee behavior is *via* the perception of small electric shocks when bees land on surfaces (Bindokas *et al*., 1988).

Follow-up experiments by Bindokas *et al*. (1989) demonstrated that bees exposed to extremely high electric fields (up to 350 kV/m) were not disturbed as long as the exposure situation did not involve landing on a conductive surface. These research results support the conclusion that bees flying in the vicinity of high voltage line (*i.e.* airborne bees) are not adversely affected.

At elevated ELF electric field levels, adverse effects can be avoided by either keeping surfaces dry or by shielding the hives from the ELF electric field with an open-mesh conductive screen, *i.e.*, a screen having a mesh size large enough not to hinder the flight of bees to and from the hive. Moreover, honeybee colonies not located directly underneath a high transmission power-line are not expected to be impacted, because the electric-field strength drops off rapidly as one moves laterally away from the right-of-way (ROW) location directly below the maximum sag point of the conductors.

Adverse effects from ELF electric fields have only been documented in studies where the electric fields measured over 50 to 100 kV/m, in high moisture conditions. If adverse effects are anticipated, ELF electric fields can be readily shielded by installing an open-mesh conductive screen over the honeybee hive or by moving the honeybee hive from directly underneath the high-voltage line. The highest projected, ground-level electric field for the Project is far below the levels discussed above where deleterious effects have been observed in honeybees.

3 Studies of Power-Line Magnetic-Field Effects on Honeybees

Some animals (including honeybees) are believed to use the earth's steady ("DC") magnetic field (~500 mG) for orientation, navigation, and migration (Kirschvink 1997 and 2001; Lohmann *et al*. 2000). The mechanism underlying this magnetic sense is thought to be microscopic ferromagnetic particles contained within sensory organs that can detect the earth's magnetic field like a "magnetic compass," *i.e. via* a twisting force that tends to line up the magnetic axis of the microscopic particles with the direction of the earth's magnetic field. Such particle alignment works for applied magnetic fields that change slowly in that, *i.e.*, it is limited to relatively slow response times, and realignment is not expected to occur when magnetic fields vary rapidly in time (*e.g.*, 60 Hz, alternating-current magnetic fields, which average to zero over 1/60th of a second).

The sensitivity of bees to changes in steady magnetic fields appears to be at about a level that is one percent of the earth's field, and honeybees may use a memorized "map" of the geomagnetic field to assist in foraging activities (Walker and Bitterman, 1989; Hsu *et al*., 2007). The magnetic component of power-line ELF-EMF could potentially exert some torque on tiny ferromagnetic particles contained within honeybees or single-molecule magnetic moments (*e.g.* "free-radical" molecules). Although magnetite particles in living organisms are plausible geomagnetic field sensors (Adair 1994; Kirschvink *et al*. 1992, 2001), functional biogenic ferromagnetic material has been established only in a limited number of organisms (for example, magnetotactic bacteria), although suspected in a variety of species (*e.g.*, honeybees). In these organisms, the magnetic interaction is believed to provide sensory guidance, and is not likely to lead to physiological malfunction or disease.

Although magnetic forces may be adequate to twist ferromagnetic particles, the response of the particles to 60-Hz magnetic fields is limited by the reversal of the power-line magnetic field direction 120 times every second. That is, the net twist over any 1/60th of a second will be zero, and because of the elevated viscosity of biological materials, only a tiny amount of twist will take place during the 1/120th of a second that the magnetic field points in a given direction. In fact, a direct test of the sensitivity of honeybees to 60-Hz magnetic fields showed behavioral effects (such as accurately selecting which dishes were sugar water *versus* plain water) only at levels of 60-Hz magnetic field above 4,300 mG, with most bees requiring at least 10,000 mG at the location of the dishes in order to impede the accuracy of their choices (Kirschvink *et al*., 1997). These levels are far higher than the maximum levels directly below the proposed CapX2020 transmission lines. As with electric fields, the magnetic field levels diminish rapidly as one moves away laterally from the centerline of the transmission-line ROW and the point of maximum circuit sag.

In the case of power-line magnetic fields, biophysical analyses have considered what might be the maximum theoretical sensitivity for organisms that have magnetic sense organs (called "magnetoreceptors"). That is, the magnetoreceptors likely utilize small pieces of magnetite, which would twist to try and orient their magnetic axes with the earth's field. The "compass needle" mechanism would not be expected to respond to power-line magnetic fields which rapidly change in size and direction, and have a time-average magnitude of zero. Even when considering a theoretical maximum sensitivity, the 60-Hz magnetic field strength necessary to possibly interfere with DC field detection is 50 mG (Adair 1994; Polk 1994), and this level is exceeded only within certain portions of the right-of-way for the proposed CapX2020 345-kV power-lines. In all other locations, the 60-Hz magnetic fields are below this value. As noted earlier, actual experiments with bees show that "the most sensitive bee" required a level of 4,300 mG power-line ELF magnetic field to discriminate the presence of this 60-Hz field.

4 Summary and Conclusions

Potential effects of low-frequency electric and magnetic fields on living organisms have been investigated, but the findings have been equivocal (NRC, 1997; Pagnac et al. 1998), and there is a lack of consistent evidence supporting outcomes that are adverse.

Scientific studies of very elevated levels of ELF electric fields (over 100 kV/m) have shown some effects on honeybee behavior and health. These documented effects are most likely caused by micro-shocks experienced by the honeybees when landing on electrically-conducting surfaces. No effects have been reported for airborne honeybees in ELF electric fields as high as 300 kV/m. ELF electric field effects on honeybees or honeybee hives can be readily prevented by placing hives outside the right-of-way, or, if honeybee hives must be located inside the right-of-way, ELF electric fields can easily be shielded by large mesh metal screening that is grounded to the earth.

There appear to be no reports by beekeepers that hives and honeybee colonies are affected by proximity to power lines and the associated magnetic fields. Special sense organs, such as "compass-needle" type of receptors for steady magnetic fields are known to exist for some animals (Kirschvink et al. 2001), but such a receptor would not be affected by power-line, 60-Hz ELF magnetic fields, which alternate in direction, and average to zero over $1/60^{th}$ of a second (Adair 1994; Polk, 1994; Valberg *et al*., 1997). The relative insensitivity to 60-Hz magnetic fields in honeybees has been demonstrated (Kirschvink *et al*., 1997).

The available research literature supports the expectation that the 60-Hz ELF-EMFs associated with the operation of the CapX2020 transmission lines will not result in adverse effects or impacts on honeybees or honeybee hives. This conclusion is supported by the information provided in the Environmental Impact Statement prepared by the Office of Energy Security.

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