High-Voltage Transmission Lines, Electric Substations, Public Health and Environment

Scientific Evidence, Regulatory Gaps, and Policy Recommendations for Protecting People, Agriculture and Wildlife

The United States routinely approves high-voltage transmission lines immediately adjacent to homes and schools despite having no federal health-based safety standard for chronic exposure, no required setbacks, no mandatory exposure assessment, and no determination of what level of long-term exposure is safe. This regulatory gap, not simply the scientific debate, is a major public health and environmental problem.

This report reviews key scientific evidence on the health and environmental effects associated with extremely low-frequency electromagnetic fields (ELF-EMFs) generated by high-voltage transmission lines, substations, and other electrical grid infrastructure. It examines research on cancer, childhood leukemia, neurodegenerative disease, reproductive health, biological mechanisms, occupational exposure, wildlife, agriculture, and ecosystems. There are enough studies linking EMF exposure to adverse health effects that hundreds of scientists have called for reducing exposure. While not every study has reported harmful effects, the overall body of evidence is substantial enough to warrant a risk mitigation approach.

This report also compares U.S. policies with those adopted in other countries, identifies deficiencies in the current U.S. regulatory framework, and presents some key recommendations for federal, state, and local policymakers to better protect public health and the environment while improving transparency, monitoring, and decision-making for future electric transmission projects.

Without health-based safety standards, how can new high-voltage transmission lines and substations be approved?

In the absence of federal health-based standards, and in the face of a growing body of scientific evidence of harm, decision makers should not and cannot assume that compliance with industry limits demonstrates protection of public health or the environment. **Where substantial scientific evidence exists, decision makers have an obligation to independently evaluate those impacts and determine whether the proposed facilities are in the public interest.**

This report is not an exhaustive review of the scientific literature. It is intended to answer a common question: Are there peer-reviewed studies reporting harmful effects from EMF exposure? It also examines how other countries are responding to the science, what policies they have adopted to reduce exposure, where the United States falls behind, and how we can build a more protective, health-based approach to EMF regulation.

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Executive Summary

The United States is undergoing its largest expansion of high-voltage electric transmission infrastructure in decades to support growing electricity demand of artificial intelligence and data centers. However there is no comprehensive federal framework to assess or manage health and environmental effects of long-term exposure to the electric and magnetic fields (EMFs) generated by high-voltage power lines.

This report summarizes selected scientific evidence related to EMF indicating that scientific evidence exists linking EMF exposure to biological effects. While not all studies have found effects, enough studies have that hundreds of scientists recommend reducing exposure to levels below industry guidelines. See emfscientist.org.

It also summarizes current U.S. policies, and international approaches to identify gaps and recommendations for public health protections. Additional issues associated with wildfire risk, bird electrocutions, habitat, pipeline interference, stray voltage, and noise are briefly summarized.

Key Findings

- **Scientific evidence supports a risk mitigation approach.** The majority of research has reported effects from exposure. Studies have found increased risks of childhood leukemia, adult cancers, Alzheimer's, oxidative stress, endocrine disruption, and other biological effects. The evidence on childhood leukemia was sufficient for the International Agency for Research on Cancer (IARC) to classify extremely low-frequency EMF magnetic fields as a Group 2B Possible Human Carcinogen in 2002 and the link continues to be found in more recent studies.
- **The United States has never completed a federal health-based review of power-frequency EMFs to develop safety standards.** Although the U.S. EPA was developing health-based safety recommendations during the 1990s, its EMF health effects program was defunded before the assessment was finalized. Since then, no federal agency has assumed responsibility for developing health-based exposure standards, nor has any agency reviewed the scientific evidence, or established a comprehensive framework to protect the public from long-term EMF exposure.
- **Industry guidelines do not address long-term health risks.** IEEE and ICNIRP exposure limits often cited by power companies were developed primarily to prevent acute effects such as nerve stimulation and electric shock. They were not designed to protect against long-term outcomes including cancer or neurological disease.
- **The United States has no comprehensive federal EMF health policy.** There are no federal health-based safety standards for exposure to power-frequency EMFs, no national EMF measuring and monitoring program, no federal requirements for industry to report measurements around transmission lines or substations, no setbacks for schools or homes, and no post-construction verification program to ensure predicted EMF exposure levels are accurate.
- **Current federal and state regulations lack transparency.** In most states, utilities are generally not required to publicly disclose electric and magnetic field levels when projects are proposed, nor to prepare publicly accessible EMF maps, nor to conduct ongoing EMF monitoring for their lines.
- **Wildlife impacts extend beyond collisions and habitat loss.** Transmission infrastructure can affect wildlife through collisions, electrocution, habitat fragmentation, and also exposure to electric and magnetic fields. Research has reported effects on bird behavior and breeding density, honey bees and other pollinators, fish, amphibians, livestock, and other wildlife. Despite these findings, there is no comprehensive federal framework that evaluates or mitigates EMF-related impacts on wildlife or ecosystem health.
- **Pollinators are unprotected:** Studies have reported that EMF may alter honey bee navigation, behavior, reproduction, and colony health, particularly when combined with other environmental stressors such as pesticides.
- **Many countries have adopted precautionary policies to better protect children.** Numerous governments, including the Netherlands, Switzerland, France, Italy, Belgium, Germany, Israel, Denmark, Norway and Finland have implemented policies, measures or

issued recommendations to reduce public exposure including protecting schools and homes with setbacks, optimizing transmission line design to reduce EMF, conducting EMF calculations before construction and publishing public guidance or EMF maps.

Policy Recommendations

This review supports modernizing U.S. policy for high voltage transmission lines, substations and other electric grid equipment by addressing EMF impacts to health and environment. Key steps include:

- Establishing a comprehensive federal regulatory framework that takes a risk mitigation approach.
- Developing health-based human and wildlife exposure limits that consider long-term exposure and vulnerable populations.
- Requiring EMF modeling and public disclosure at the beginning of project proposals.
- Conducting post-construction measurements to verify predicted exposures.
- Establishing protective siting policies for schools, homes, childcare centers, hospitals, and parks.
- Expanding research and national surveillance on EMF exposure, health and environmental outcomes.
- Incorporating wildlife and pollinator protection into transmission planning and environmental review.
- Evaluating international best practices that have successfully reduced public exposure while maintaining reliable electric infrastructure.

As the United States invests billions of dollars in expanding its electric grid, there are opportunities to improve safety and transparency to align infrastructure planning with the best available scientific evidence and international practices. Until adequate regulations are in place, governments should reduce exposure, especially for children and the medically vulnerable.

Science on Health Risks Associated with Proximity to High Voltage Lines and Electric Substations

Magnetic fields from power lines and electrical grid infrastructure can induce electric fields inside body tissues. A significant body of research reports associations with childhood leukemia, as well as adult cancers, Alzheimer's, miscarriage, hormone disruption and other adverse effects. Numerous countries have advanced policies to restrict magnetic field EMF exposure to levels below 3 or 4 mG, the levels associated with childhood leukemia.

Notable scientific reviews and reports on EMF over the years

These reports do not conclude safety but rather, they report on the complexity of the scientific research and recommend **more research.**

- **The International Agency for Research on Cancer (IARC)** classified extremely low-frequency (ELF) magnetic fields as Group 2B, "possibly carcinogenic to humans," in 2002 based primarily on consistent epidemiological evidence associating EMF exposure in the home to increased risk of childhood leukemia. IARC's final conclusion is:

  > Overall, extremely low frequency magnetic fields were evaluated as possibly carcinogenic to humans (IIB), based on the statistical association of higher level residential ELF magnetic fields and increased risk for childhood leukaemia.

  Over the last two decades since the WHO IARC classification, research studies in countries around the world have continued to report increased childhood leukemia.

- **National Institute of Environmental Health Sciences (1998)** evaluated the research and classified ELF EMFs as possibly carcinogenic based on chronic lymphocytic leukemia associated with occupational exposure.
- **The California Department of Health (2002)** classified magnetic field EMF as at least group 2B in the states' EMF Program report. The report, "An Evaluation of the Possible Risks From Electric and Magnetic Fields (EMFs) From Power Lines, Internal Wiring, Electrical Occupations and Appliances" concluded that EMFs may increase risks of childhood leukemia, brain cancer, ALS, and miscarriage.
- **The Netherlands Health Council (2018/2022)** reports reaffirmed links to cancer and recommended reducing ELF-EMF. In 2013, houses under 380–220 kV lines were bought out because of the ELF EMF exposure. In 2023, the government updated its policy to prevent new situations where people stay for a long time in the area near overhead power lines and substations and where the magnetic field exceeds 4 mG.
- **The French Agency for Food, Environmental and Occupational Health & Safety (2019)** published its Report on the Health Effects of Exposure to Low-Frequency Electromagnetic Fields, reaffirmed the scientific evidence linking childhood leukemia to exposure and called for minimizing exposure in sensitive areas such as schools, hospitals, and for pregnant women.
- **The European Commission Scientific Committee on Health, Environmental and Emerging Risks reports** (2015 and 2024 preliminary) are often misleadingly put forward as proof of safety. While these reports do not conclude that health effects are proven, they do document numerous studies linking exposure to adverse effects and recommend more research to fully investigate various health endpoints. For example, their 2024 preliminary opinion states:

  "In the case of ELF-EMF and their association with childhood leukaemia, further studies are recommended, using appropriate animal models for studying acute lymphoblastic leukaemia. Moreover, more in vitro hypothesis-driven studies are needed, which can elucidate the potential interaction mechanisms of ELF-EMF at the cellular level. With respect to all other neoplastic diseases, more epidemiological studies of adequate statistical power need to be conducted. Finally, it is important to perform further research on the quantification of the potential impact of ELF-EMF in the area of public health, also incorporating real world data. In the case of ELF-EMF and their potential impacts on flora

and fauna (both terrestrial and marine), it is recommended that further studies are undertaken."

Regarding wildlife their 2024 preliminary opinion states, "However, honeybees can also perceive ELF-EMF but with a lower sensitivity than shown for static fields. The results reviewed by Pophof et al. (2023) indicate that 'short-time exposure to magnetic fields, at levels that could be encountered in beehives placed under power lines or during foraging flights, could affect the ability of bees to forage and pollinate crops and to respond appropriately to environmental stimuli'. Moreover, two studies with honeybees reported results of field investigations (Lupi et al., 2020; 2021) that have shown negative effects of electric and magnetic fields from power lines in combination with pesticides. Risk to pollinators was also studied in Vanbergen et al. (2019) who concluded that evidence of impacts is inconclusive, due to a lack of high-quality field studies. A recent paper by MolinaMontenegro et al. (2023) concluded "conclusive evidence of detrimental impacts of EMF on honeybee's pollination behaviour, leading to negative effects on plant community". At the same time three review articles by Levitt et al. (2021a,b), as well as systematic reviews by Thill et al. (2023) on impacts on insects demonstrate the research activity within this area is very active, identifying and addressing a number of research gaps."

In short, safety is not established.

The U.S. EPA's abandoned effort to develop health-based EMF safety standards.

The United States has never established federal health-based exposure limits for the EMF exposure from power lines and substations. The history of how this occurred is important because the absence of a health-based limit does not mean the absence of scientific evidence. Rather, it reflects a federal regulatory process that was never finished and the power of the electric companies to impact science and policy.

Before Congress eliminated its funding, the EPA's robust EMF research program conducted extensive scientific research on the biological effects of non-ionizing EMFs. EPA had released a draft report that recommended designating powerline-frequency EMFs as a "probable human carcinogen" but that conclusion was deleted from the subsequently released draft, which stated EMFs was a "possible", but not proven, cause of cancer in humans. Despite repeated review by expert agencies, the report was ultimately shelved and never finalized.

The EPA's EMF research to develop health-based safety standards was fully discontinued after Congress eliminated funding. As a result, the United States never adopted any federal safety limits for EMF nor has there been any scientific review for decades. The absence of federal EMF activities paired with limited state regulation has resulted in permitting decisions for high-voltage transmission lines relying on industry-developed engineering standards instead of health-based standards. **The limits of the IEEE and ICNIRP primarily address short-term,**

acute effects (such as nerve stimulation), but not effects of long-term EMF exposure health effects. Their exposure limits are set thousands of times higher than the EMF magnetic field levels associated with childhood leukemia.

Hundreds of scientists recommend reducing public and environmental exposure

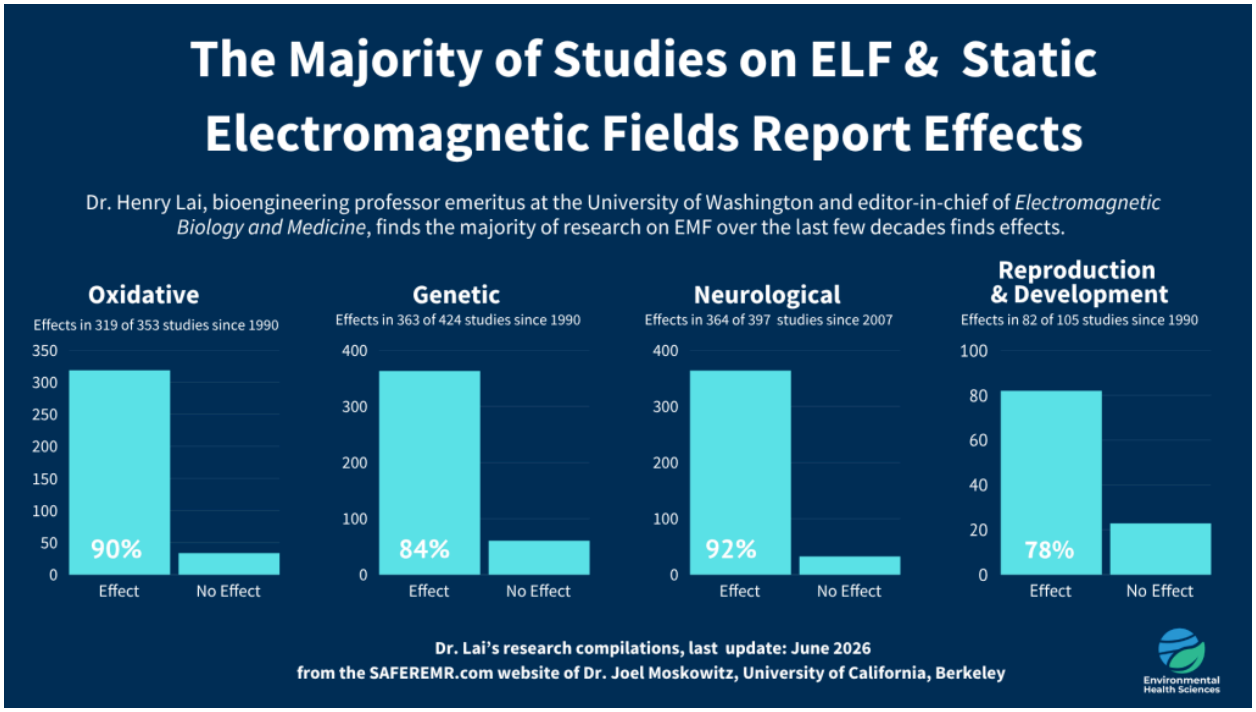
There is no consensus for safety when it comes to high voltage power lines, electric substations and other sources of EMF.

The EMF Scientist Appeal was first released in 2015 and is now signed by over 259 scientists from 41 countries who have peer-reviewed publications on electromagnetic fields. They request that the United Nations and all Member States in the World Health Organization exert strong leadership in fostering the development of more protective EMF guidelines, encouraging precautionary measures, and educating the public about health risks, particularly risk to children and fetal development.

> "Based upon peer-reviewed, published research, we have serious concerns regarding the ubiquitous and increasing exposure to EMF generated by electric and wireless devices…
> Numerous recent scientific publications have shown that EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life."

The majority of studies link EMF exposure to a broad range of impacts.

While not all studies have found effects, and the majority have reported associations.



Dr. Henry Lai, Professor Emeritus at the University of Washington, Editor Emeritus of the journal, Electromagnetic Biology and Medicine, and an emeritus member of the International Commission on the Biological Effects of EMF, has compiled summaries of the research on the biological effects of exposure to radio frequency (RFR) and extremely low frequency (ELF) and static electromagnetic fields (EMF). His set of abstracts, which covers the period from 1990 constitutes a comprehensive collection of the peer-reviewed research.

Dr. Lai reports that the preponderance of research has found that exposure to RFR or ELF EMF produces oxidative effects or free radicals, and damages DNA. This information is posted on Dr. Joel Moskowitz website SaferEMR.com.

Summary of Results for ELF (Last major update: June 8, 2026)

- 90% (n=313) of 353 ELF/static EMF oxidative effects (or free radical) studies published since 1990 reported significant effects.
- 84% (n=363) of 424 ELF/static EMF genetic effects studies published since 1990 reported significant effects, including 92% (n=232) of 252 studies of gene expression.
- 92% (n=364) of 397 ELF/static EMF neurological studies published since 2007 reported significant effects.
- 78% (n=82) of 105 ELF/static EMF reproduction and development studies published since 1990 reported significant effects.

A recent 2026 letter by Dr. David Carpenter outlines the scientific evidence supporting strong setbacks between high-voltage transmission lines, substations, homes, and schools.

UNIVERSITY AT ALBANY
State University of New York

Institute for Health and the Environment
WHO Collaborating Center in Environmental Health

Re: Scientific Justification for Strict Setback Distances for High Voltage Transmission Lines and Substations from Homes and Schools

I am a public health physician and Director of the Institute for Health and the Environment at the University at Albany, SUNY, a World Health Organization Collaborating Centre. I have researched non-ionizing electromagnetic fields (EMFs) for over four decades. In the 1980s, I served as Executive Secretary of the New York Powerlines Project, a $5 million study of 60 Hz magnetic fields that included research reporting an increased risk of childhood leukemia associated with elevated residential magnetic fields from power lines. I later served as New York State's spokesperson on EMF issues, Director of the Wadsworth Laboratory at the New York State Department of Health, Dean of the School of Public Health at the University at Albany and have testified before the President's Cancer Panel and the U.S. Congress on EMF and health.

Exposure to elevated power-frequency magnetic fields is associated with an increased risk of cancer, particularly childhood leukemia, as well as leukemia, brain cancer, and breast cancer in adults. The association between residential magnetic field exposure and childhood leukemia has been replicated in numerous studies conducted in multiple countries. There is also strong evidence linking long-term exposure to an increased risk of Alzheimer's disease. These are serious, often fatal diseases.

Reliance on the exposure limits of the Institute of Electrical and Electronics Engineers (IEEE) or International Commission on Non-Ionizing Radiation Protection (ICNIRP) does not protect the public, especially children, from the health impacts of long-term exposure. There is definitive evidence in the peer-reviewed scientific literature that power-frequency EMF can produce biological effects at field strengths well below these limits. Importantly, the IEEE and ICNIRP guidelines are outdated and inadequate, as they were only designed to address short-term exposure effects and not the chronic, continuous exposures experienced by people living near high-voltage power lines for many hours each day over many years.

It is the responsibility of every government to protect its citizens from avoidable risks. In total, the scientific evidence, especially leukemia, brain and breast cancer, and Alzheimer's disease, associated with EMF exposure is sufficiently strong to warrant policy action. I urge governments to do everything in their power to mitigate the serious health risks from high-voltage transmission lines and substations by adopting protective setbacks for homes and schools and implementing evidence-based measures to minimize EMF exposures, such as undergrounding and low-EMF engineering design.

High-voltage transmission lines and electric substations should be located as far away from homes, schools, and childcare facilities as possible. I am attaching a publication that presents the scientific evidence behind these recommendations.

Yours sincerely,

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The BioInitiative Report is a landmark scientific review on the biological and health effects of electromagnetic fields (EMFs) and radiofrequency (RF) radiation. It was written by 29 experts from 10 countries, including 10 medical doctors and 21 PhDs, all of whom are recognized authorities in their respective fields. The authors include three former presidents and five members of the Bioelectromagnetics Society. Dr. Carl F. Blackman, for example, is a former research scientist in the Environmental Carcinogenesis Division of the US Environmental Protection Agency and served on the World Health Organization committee to evaluate the health implications of radiofrequency radiation exposure.

The updated 2012 and 2017 editions incorporated over 1,800 new peer-reviewed studies. Most of the chapters of the original 2007 BioInitiative Report were published in 2009 in the peer-reviewed journal Pathophysiology, a respected international journal that focuses on the biological mechanisms underlying disease.

> "The time for arguing whether EMF health effects exist is over. We know they exist and that they result in human disease."
>
> "The work of Martin Blank and Reba Goodman of Columbia University has established that stress proteins are produced by ELF-EMF and RFR at levels far below current safety standards allow. Further, they think DNA is actually a very good fractal RF-antenna which is very sensitive to low doses of EMF, and may induce the cellular processes that result in chronic 'unrelenting' stress. That daily environmental levels of ELF-EMF and RFR can and do throw the human body into stress protein response mode (out of homeostasis) is a fundamental and continuous insult. Chronic exposures can then result in chronic ill-health."

Studies link EMF to childhood leukemia and cancer.

More than four decades of epidemiological research from around the world have linked long-term exposure to magnetic fields from high-voltage power lines with an increased risk of childhood leukemia and other cancers. The evidence includes landmark studies, pooled analyses, meta-analyses, and recent systematic reviews showing consistent associations across multiple countries and populations.

The World Health Organization International Agency for Research on Cancer classified ELF-EMF magnetic fields as a "possible" human carcinogen in 2002, based largely on evidence linking power line exposure to childhood leukemia.

- Malagoli et al. (2023), a population-based case-control study published in *Environmental Research* found children living within 100 meters of high-voltage power lines had approximately twice the risk of childhood leukemia compared with those living at least

400 meters away. Analyses showed that leukemia risk increased as residential distance to power lines decreased below 100 meters.

- A systematic review by Brabant et al. (2022) of 38 studies in *Reviews on Environmental Health* found that long-term exposure to magnetic fields above 4 milligauss (mG) was associated with increased risk of childhood leukemia, particularly acute lymphoblastic leukemia.
- A 2021 meta-analysis of 33 studies published in *PLOS 1* concluded a significant association between powerline ELF exposure and childhood leukemia, with possible dose-response effects.
- Correa-Correa et al. 2025 published in *Environmental Research* found children exposed to 4 milligauss (ELF-EMF) in their homes had a significantly increased risk of central nervous system tumors. Prolonged tablet use also increased CNST risk, especially in children aged 6–10. Residential ELF-MF exposure was measured over 24 h.
- Carles et al. 2020, a major French population-based study published in *Environmental Research*, found that long-term residence within 50 meters (164 feet) of high-voltage power lines was associated with nearly three times the risk of brain tumors and nearly five times the risk of glioma brain cancer.
- Sohrabi et al., (2010), published in the *Asian Pacific Journal of Cancer* found that living within 600 meters of high-voltage power lines was associated with a 2.61-fold increased risk of acute lymphoblastic leukemia (ALL), concluding that proximity to high-voltage power lines is a risk factor for childhood ALL.
- Feizi and Arabi (2007), published in the *Asian Pacific Journal of Cancer Prevention*, reported an association between childhood acute leukemia and residential exposure to magnetic fields generated by high-voltage overhead power lines in Iran.
- Kabuto et al. (2006), published in the *International Journal of Cancer*, found that Japanese children exposed to residential magnetic fields above 4 mG had an increased risk of childhood leukemia compared with children exposed to lower magnetic field levels.
- Draper et al. (2005), published in the *British Medical Journal* analyzed childhood cancer cases in England and Wales and found that children born within 200 meters of high-voltage power lines had a 69% higher risk of childhood leukemia compared with those living more than 600 meters away.
- Schüz et al. (2001), published in the *International Journal of Cancer*, reported that German children with long-term residential magnetic field exposures of approximately 4 milligauss (0.4 μT) or greater had an elevated risk of childhood leukemia, supporting findings from earlier Scandinavian studies.
- Thériault and Li (1997), published in Occupational and Environmental Medicine, conducted a meta-analysis of studies of people living near high-voltage transmission lines and found that residential exposure to magnetic fields of 2 mG and above was associated with an increased risk of leukemia, with risk increasing at 3 mG, 4 mG, and 10 mG. The authors concluded that the evidence consistently supports an association.
- Feychting and Ahlbom (1993), published in the *American Journal of Epidemiology*, was one of the landmark studies reporting an increased risk of childhood leukemia among

children living near high-voltage power lines, particularly at estimated magnetic field exposures of ≥ 2 mG, and was influential in the IARC classification.

- Wertheimer and Leeper (1979), published in the *American Journal of Epidemiology*, was the first epidemiological study to report an association. Children living in homes with wiring indicative of higher current flow had a higher risk of childhood cancer, particularly leukemia, and the association appeared to be dose-related and strongest among children who had lived at the same residence throughout their lives

Studies have found poorer survival in children diagnosed with cancer who are exposed to higher magnetic field levels.

- Foliart et al. 2006 published in the *British Journal of Cancer* found poorer survival rates in U.S. children with acute lymphoblastic leukemia (ALL) exposed to magnetic fields above 3 mG compared with those exposed to magnetic fields below 1 mG.
- A German follow-up study by Svendsen et al. 2007 published in *Cancer Epidemiology, Biomarkers & Prevention* found in children with acute lymphoblastic leukemia (ALL) that children exposed to residential magnetic fields above 2 mG after diagnosis had poorer survival than those exposed to lower field levels. After adjusting for prognostic risk factors, children exposed above 2 mG had an approximately threefold higher risk of death.

Industry funding has been found to impact study results.

A major review of the research on EMF from power lines and cancer published in *Environmental Research* found magnetic field EMF exposure increases risk of adult leukemia, brain and breast cancer. The review also compared industry funded research to independently funded studies and found "almost all government or independent studies find either a statistically significant association between magnetic field exposure and childhood leukemia, or an elevated risk of at least OR = 1.5, while almost all industry supported studies fail to find any significant or even suggestive association."

"The evidence that magnetic fields increase the risk of cancer is neither inconsistent nor inconclusive. Furthermore, adults are also at risk, not just children, and there is strong evidence for cancers in addition to leukemia, particularly brain and breast cancer." - David O. Carpenter, M.D., in *Environmental Research* "Extremely low frequency electromagnetic fields and cancer: How source of funding affects results"

"Controversy, or at least the appearance of controversy, regarding the health risks associated with environmental electromagnetic fields has developed because the emerging scientific picture runs markedly counter to the long-standing interests of some industries and government agencies in unbridled use of the electromagnetic spectrum. The existence of a link between electromagnetic fields in the environment and disease has been established despite the fact that many important details regarding it remain undiscovered." - Andrew Marino

Children Are More Vulnerable to EMF Exposure

Children are more vulnerable to environmental exposures, including non-ionizing EMF, because their bodies and brains are still developing and they have more years of life ahead for diseases with long latency periods to develop. Exposure during childhood or pregnancy can have serious impacts later in life. In addition to the consistent association with childhood leukemia, several studies on EMF suggest that early-life exposure may increase the risk of diseases that do not appear until adulthood.

- Lowenthal et al. (2007), published in the *Internal Medicine Journal,* found that adults who lived within 300 meters of a high-voltage power line during childhood had significantly increased risks of lymphoproliferative and myeloproliferative cancers, including certain types of leukemia. Risk was more than threefold higher for those living within 300 meters during the first 15 years of life and nearly fivefold higher for those exposed during the first 5 years.
- Li, McLaughlin, and Infante-Rivard (2009), a Canadian study, published in *Cancer Causes & Control*, on children of mothers who were employed as sewing machine operators (a higher EMF occupation), during their pregnancy had approximately twice the risk of childhood brain tumors.
- Infante-Rivard and Deadman (2003), researchers from McGill University, published in *Epidemiology,* found that children whose mothers had the highest occupational exposure to extremely low-frequency magnetic fields during pregnancy had an increased risk of childhood leukemia, with the highest exposure associated with a 2.5-fold increased risk.
- Khan et al. (2022) published in *Occupational & Environmental Medicine* found that childhood residential exposure to extremely low frequency magnetic fields (ELF-EMF) was associated with a more than twofold increased risk of developing melanoma in adulthood. (Tynes et al. (2003) published in *Occupational and Environmental Medicine* has also reported an association with malignant melanoma.

Studies link EMF to Alzheimer's disease and other types of dementia.

Ghiasvand et al. (2026) published in the *Journal of Alzheimer's Disease* reviewed various exposures and states, "Occupational exposures to toxic metals, pesticides, and electromagnetic fields were also associated with higher neurodegeneration risk."

Here are some studies to know:

- Sandoval-Diez et. al. (2026), a 18-year nationwide cohort study of over 3.5 million people published in *Environment International* found increased risk of dementia and Alzheimer's mortality beginning around 0.5 mG, with stronger associations observed in the 1–3 mG range, an EMF range commonly found in homes close to electrical grid infrastructure like power lines and substations.
- Jalilian et al. (2018), published in *Neurotoxicology*, conducted a systematic review and meta-analysis of occupational studies and found that workers exposed to

extremely low-frequency (ELF) magnetic fields had a significantly increased risk of Alzheimer's disease.

- Davanipour et al. (2013) published in the *Journal of Advances in Medicine and Medical Research*, an National Institutes of Health supported study reported associations between high occupational ELF-EMF exposure and cognitive dysfunction and dementia. Smoking and older age increased the effects.
- Huss et al. (2009), published in the American Journal of Epidemiology, found an increased risk of Alzheimer's mortality associated with long-term residential proximity within 50 meters of high-voltage power lines.

Studies link EMF to reproductive impacts, including miscarriage.

Researchers from the Kaiser Permanente Division of Research have published a series of prospective studies examining outcomes associated with magnetic field exposure during pregnancy. In these studies, pregnant women wore personal magnetic field meters to objectively measure their exposure, and researchers then followed the pregnancies and, in many cases, the children for years to evaluate health outcomes.

Their findings include:

- Li et al. (2017), published in Scientific Reports, found higher prenatal EMF associated with a 2.72-fold increased risk of miscarriage, consistent with an earlier study by Li et al (2002) published in *Epidemiology.*
- Li et al. (2012), published in Scientific Reports, found higher prenatal exposure associated with an increased risk of childhood obesity, with a dose-response relationship and up to a 2.3-fold higher risk among children followed through the end of the study.
- Li et al. (2011)**,** published in the *Archives of Pediatrics & Adolescent Medicine,* found pregnant women with the highest magnetic field exposure defined as a median 24-hour exposure greater than 2.0 mG, had children with more than a 3.5-fold increased risk of asthma, with a clear dose-response relationship. News: Microwaves and Asthma: Exposure to Magnetic Fields During Pregnancy Ups Asthma Risk Among Newborns
- Su et al. (2014), published in *PLoS One*, conducted a cross-sectional study of 149 women undergoing elective first-trimester abortions to investigate whether everyday exposure to EMF was associated with embryonic development. Participants wore an magnetic field EMF meter for 24 hours to measure their personal magnetic field exposure. The study found that higher maternal magnetic field exposure was associated with shorter embryonic bud length.
- Li et al. (2010), published in Reproductive Toxicology, studied men's exposure and found that higher daily exposure to magnetic fields (MFs) at 1.6 mG was associated with a two-fold increased risk of poor sperm quality (abnormal motility and morphology).
- Irani et al (2023) published in *Malaysian Journal of Medical Sciences* is a systematic review and meta-analysis of human studies that found that higher non-ionizing

electromagnetic-field exposure was associated with a significantly increased risk of miscarriage.

Studies Link EMF to breast cancer.

The first study on EMF and breast cancer was published by Matanoski et al. 1991 in *The Lancet* reporting on a study that found an increased relative risk of male breast cancer among U.S. telephone company workers (such as linemen and central office installers) who had higher occupational exposure. Since that date, evidence linking magnetic field exposure to breast cancer is strongest for male breast cancer, while some, but not all, studies of female breast cancer have also reported positive associations. Studies also suggest that ELF magnetic field exposure may enhance and/or activate molecular pathways involved in breast cancer and cancer progression.

- Sun et al. (2023), a meta-analysis of 18 studies on EMF exposure and male breast cancer published in the *Asian Pacific Journal of Cancer Prevention* found EMF significantly associated with increased risk of male breast cancer.
- Lazzarini et al. (2023), published in *Ecotoxicology and Environmental Safety* found that exposing human breast cancer cells to a 50 Hz magnetic field increased cell growth, migration, and invasion, while activating genes and molecular pathways associated with breast cancer progression.
- Grundy et al. (2016), published in *Cancer Medicine*, found men exposed to 6 mG or greater had an elevated risk of breast cancer and those exposed for 30 years or more had nearly a threefold increased risk compared with men exposed to less than 3 mG.
- Di Donato et al. (2023), published in *Cells*, exposed human breast cancer cells to a 50 Hz magnetic field for 4 hours and found numerous cellular and protein changes as well as faster growth of cancer cells.
- Zhao et al. (2014), a meta-analysis of sixteen case control studies published in the European Journal of Gynaecological Oncology found that ELF magnetic field exposure was associated with a statistically significant increased risk of breast cancer in premenopausal women.
- Kliukiene et al. (2004), published in the *American Journal of Epidemiology*, found that women living near high-voltage power lines with residential magnetic field exposure had a higher risk of breast cancer compared with unexposed women.
- Fedrowitz and Loscher conducted a series of studies that found that exposing rats to magnetic fields significantly increased cell proliferation in the mammary glands of a specific strain of rats (published in *Oncology* in 2005) and long-term exposure increased the incidence of mammary adenocarcinomas (published in *Carcinogenesis* in 2008).

Studies on occupational exposure have reported adverse effects.

- Gunnarsson and Bodin (2019), a meta-analysis of 19 occupational studies on neurodegenerative disease published in the International Journal of Environmental

Research and Public Health, found that occupational EMF exposure was associated with a higher risk of ALS and Alzheimer's disease.

- Pedersen et al. (2017), published in the International Archives of Occupational and Environmental Health, found that Danish utility workers with the highest occupational exposure to magnetic fields had elevated risks of dementia, motor neurone disease, multiple sclerosis, and epilepsy.
- Huss et al. (2018), published in Environmental Research, reported in a meta-analysis that occupational exposure to magnetic fields may affect specific hematolymphopoietic malignancies rather than “all leukaemia” as exposure was associated with an increased risk of acute myeloid leukemia (AML) specifically, particularly among workers with long-term high exposure, in line with previous research studies.
- Dominici et al. (2011), published in the International Journal of Hygiene and Environmental Health, found that welders occupationally exposed to extremely low-frequency magnetic fields had significantly increased DNA damage, with micronuclei frequency increasing in a dose-response relationship with ELF-MF exposure.
- Davanipour et al. (2007), researchers from the Department of Neurology, Keck School of Medicine, University of Southern California, published in *BMC Neurology,* results of their case-control study using patients from the California Alzheimer's Disease Diagnosis and Treatment Centers which found that occupational exposure to extremely low-frequency magnetic fields was associated with increased risk of Alzheimer's disease.
- Charles et al. (2003), published in the *American Journal of Epidemiology*, found that U.S. electric utility workers with the highest occupational exposure to electromagnetic fields (EMFs) were about twice as likely to die from prostate cancer compared with workers with lower EMF exposure, even after adjusting for PCB exposure and other potential confounding factors.
- Minder et al. (2001), published in the *American Journal of Epidemiology,* found that Swiss railway workers with the highest occupational exposure to extremely low frequency (ELF) magnetic fields had a 2.4-fold increased leukemia mortality, with leukemia risk increasing significantly as cumulative magnetic field exposure and years exposed to fields ≥10 μT increased, supporting an association between heavy ELF magnetic field exposure and leukemia.
- Jalilian et al. (2018), published in *Neurotoxicology*, conducted a systematic review and meta-analysis of occupational studies and found that workers exposed to extremely low-frequency (ELF) magnetic fields had a significantly increased risk of Alzheimer's disease.

Studies report non-ionizing EMF can have a range of biological effects.

A substantial body of research shows that electromagnetic fields (EMFs) can affect multiple biological systems through mechanisms including oxidative stress, DNA damage, endocrine disruption, altered cell signaling, and changes in nervous system function.

"Evidence supporting EMF-induced oxidative stress is substantial. Numerous studies report that exposure to EMFs results in oxidative stress across various tissues, increasing free radical concentrations and influencing radical pair recombination processes…Recent human observational studies and meta-analyses have also suggested increased oxidative stress as a clinical pattern of toxic health effects associated with EMF exposure [**32**]. Oxidative stress thus serves as a central, downstream pathway. Multiple lines of evidence converge on oxidative stress as a key mechanism, with detailed explanations illustrating how EMFs, through non-thermal means like ion channel modulation, can lead to ROS overproduction, which subsequently causes cellular damage."
- A Narrative Review on the Influence of Electromagnetic Fields Below 100 kHz on the Endocrine System

- Tojza et al. (2026) published in Applied Sciences reviewed the studies on EMF and the endocrine system concluding that animal studies consistently show EMF from power infrastructure can alter melatonin secretion, stress hormones, thyroid function, and reproductive hormones. While human studies remain limited, the authors state the widespread chronic exposure justifies precautionary consideration and more rigorous long-term research.
- Danho (2025) published in *Cureus* found "EMFs negatively affect a wide array of biological systems of living organisms, including mechanisms of oxidative stress, inflammatory responses, and disruptions in cellular, physiological, and ecological processes.
- Lai and Levitt (2023), published in *Reviews on Environmental Health*, concluded that non-ionizing electromagnetic fields can trigger a cellular stress response involving oxidative stress, DNA, protein, and lipid damage, activating repair pathways and other biological responses that may influence cancer risk, neurodegenerative diseases, nerve regeneration depending on exposure conditions.
- Giorgi and Del Re (2021), a review on epigenetic changes and EMF, published in Cell and Tissue Research found "available evidence indicates that ELF-MF exposure can be associated with epigenetic changes, including DNA methylation, modifications of histones and microRNA expression. They noted that epigenetic alterations are implicated in diseases including cancer and neurological disorders and called for further research.
- Lai (2021), published in Electromagnetic Biology and Medicine, reviewed the studies on genetic effects of non-ionizing EMF reporting that many studies reported effects in cells and animals after exposure to EMF at intensities similar to those in the public and occupational environments. While the energy level is not sufficient to cause direct breakage of chemical bonds within molecules, the effects are probably indirect and secondary to other induced chemical changes in the cell via multiple inter-dependent biological mechanisms.

Scientists have long stated that EMF exposure creates a "cellular stress response.

Electromagnetic fields (EMFs) can act as a biological stressor. Beginning in the 1960s and 1970s, pioneering researchers including Robert O. Becker and Andrew A. Marino demonstrated that extremely weak electric and magnetic fields, at levels well below those which caused nerve stimulation and electrical shock, could alter normal biological function. Becker coined the term "electrical pollution" to describe the rapidly increasing presence of artificial manmade electromagnetic fields in the environment which he warned was a novel environmental stressor.

Marino has long argued that his research clearly shows that chronic EMF exposure is a biological stressor. The EMF exposure places physiological demands on the organism that, when sustained or sufficiently intense, may contribute to a wide range of adverse health effects depending on the individual's susceptibility. Rather than producing one specific disease, chronic activation of the stress response can disrupt normal cellular regulation and increase vulnerability to numerous biological abnormalities and disease processes.

“Electromagnetic energy does not act only on a single target organ. There is a clear pattern in the literature indicating that electromagnetic energy is a biological stressor—that it places a nonspecific physiological demand on the exposed organism. When the organism’s capacity to resist has been exceeded, a clinical sign—an effect—is manifested whose nature depends in part on the predisposition of the exposed subject. It follows, therefore that the exposure of a substantial part of the population in an uncontrolled, random, and essentially involuntary manner amounts to a significant public-health (and ethical) problem.”

Marino synthesized findings from multiple experimental and epidemiological studies into a single illustration in his 1984 paper in a graphic entitled "Power Frequency Fields of a 765 kV Line in Relation to Observed Biological Effects."

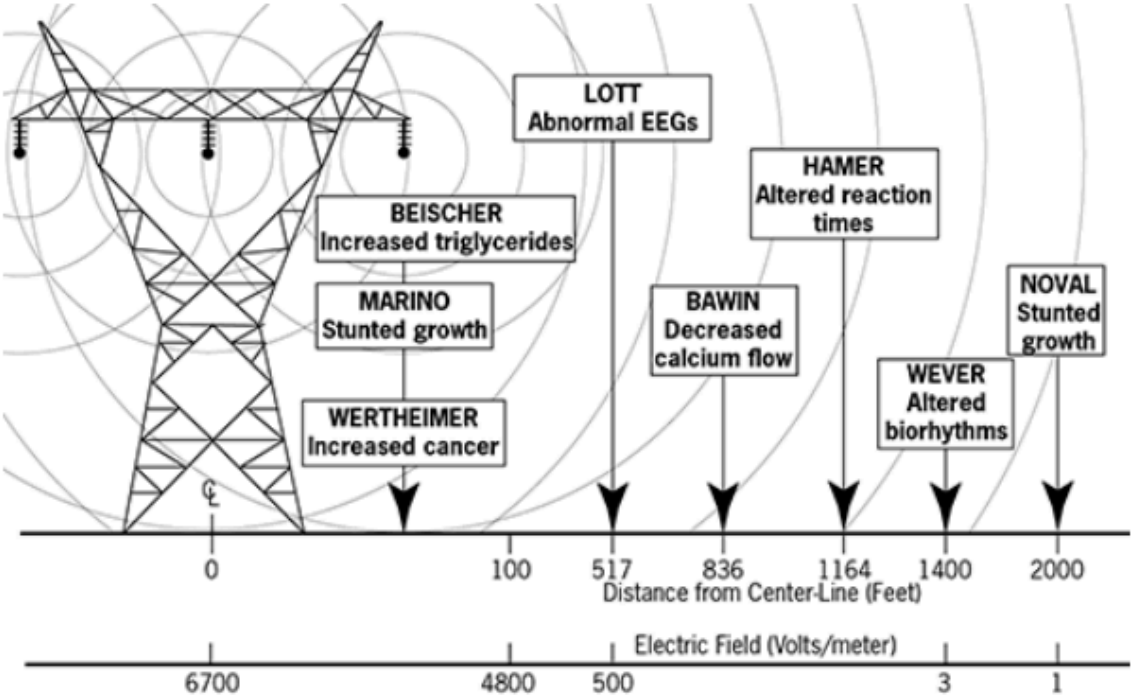

FIGURE 2: Power Frequency Fields of a 765 kV Line in Relation to Observed Biological Effects

Marino noted that several studies reporting increased childhood cancer, altered growth, and elevated triglycerides involved field strengths found within approximately the first 100 feet of a 765 kV high-voltage transmission line, while five additional studies reported biological effects—including abnormal EEGs, altered calcium flow, changes in reaction time, disrupted circadian rhythms, and stunted growth—at field intensities equivalent to those occurring hundreds to thousands of feet from a 765-kV line. He concluded that these examples represented only a portion of the available literature, noting that "there are many other similar reports of biological effects."

Marino conducted numerous animal studies and biophysical calculations that showed electromagnetic energy penetrates the body and can cause physiological effects. As an example, in 1980 Marino, Becker, and Ullrich conducted one of the first multigenerational studies of power-frequency electric fields, continuously exposing mice to 60 Hz electric fields of field strengths that Marino later noted are comparable to those found within approximately the first 100 feet of a typical 765-kV transmission line. The study, published in Experientia, found

that across three successive generations, exposed mice exhibited reduced body weight and increased mortality, particularly in the vertically exposed group.

In 1990 Marino's peer-reviewed meta-analysis published in the Journal of Bioelectricity, reviewed eight multigenerational mouse experiments conducted over a 15-year period involving continuous exposure to 60-Hz electric fields. Across these studies, he found that the exposure consistently altered development and developmental variability, with statistically significant effects observed in all eight experiments. Although these effects did not follow a simple linear dose-response relationship, Marino concludes that the exposure elicited different physiological responses depending on the organism's internal regulatory systems.

Read a list of Andrew Marino's published papers here

- Tokalov and Gutzeit (2004), published in *Environmental Research*, found that exposing human myeloid leukemia cells to 50 Hz magnetic fields significantly increased expression of HSP70 stress-response genes, demonstrating that extremely low-frequency electromagnetic fields can activate the cellular stress response. The authors concluded that ELF-EMFs may alter cellular homeostasis and that their biological effects follow an unusual non-linear dose-response pattern.

- Blank and Goodman (2009), scientists who together with colleagues have published numerous studies on the issue, published a foundational paper in Pathophysiology entitled "Electromagnetic fields stress living cells" concluding that both extremely low-frequency (ELF) and radiofrequency (RF) electromagnetic fields activate cellular stress responses, including the expression of HSP70 stress proteins, and argued that EMF safety standards should be based on biological effects.

Studies link EMF to neurological impacts.

- Bertagna et al. (2021), published in *Annals of New York Academy of Sciences* conducted a systematic review of studies published between 2005 and 2020 on neuronal ion channels and found that extremely low-frequency (ELF) electromagnetic fields can alter voltage-gated ion channels at multiple levels, including their gating dynamics, ion conductance, membrane insertion, and gene and protein expression. The authors state that, "this systematic review reports significant correlation between EMFs and multiple changes in the electrophysiological properties of diverse neuronal tissues," concluding that voltage-gated calcium channels (VGCCs) are an important transducer of ELF-EMF effects in neurons, where they play a central role in neurotransmitter release, synaptic plasticity, neuronal communication, neurite outgrowth, and gene expression.
- Lai (2022), published in Electromagnetic Biology and Medicine, reviewed studies showing that static and extremely low-frequency (ELF) electromagnetic fields can affect

neurotransmitters, memory, learning, behavior, and neurological diseases, with evidence suggesting that oxidative stress and free radicals may play an important role in these effects. Depending on the conditions of exposure, either harmful or beneficial effects could result. Further research is needed, especially to extrapolate the animal studies to humans.

- Ghadamgahi et al. (2016) published in Environmental Monitoring and Assessment evaluated the working memory in 10- to 12-year-old boys attending elementary schools located near a high-voltage electrical substation and found students attending the schools with higher magnetic field levels performed significantly worse on a standardized working memory assessment adapted from the Wechsler Intelligence Scale for Children (WISC-IV). “It is concluded that extremely low frequency magnetic field exposure may have a negative impact on the working memory of children, but further studies are necessary to reach a definitive conclusion.”
- Pall (2013) published in Future Neurology proposed that low-intensity EMFs can activate voltage-gated calcium channels (VGCCs) by exerting electrical forces on the channel's voltage sensor, leading to intracellular calcium overload and downstream oxidative stress.

Sleep, depression and suicide

- Hosseinabadi et al. (2018), published in *Electromagnetic Biology and Medicine*, found that long-term occupational exposure to ELF-EMF was associated with poorer sleep quality and increased stress, depression, and anxiety among power plant workers.
- Weerasinghe et al. (2024), published in the *International Journal of Occupational Safety and Ergonomics,* found that higher exposure to extremely low-frequency magnetic fields (ELF-MFs) among industrial workers in Korea was associated with differences in systolic blood pressure and deep sleep.
- Barsam et al. (2012), published in the *Iranian Journal of Environmental Health Science & Engineering,* found that workers exposed to ELF-EMFs in high-voltage substations took significantly longer to fall asleep. Exposed workers had lower average sleep duration as compared with control subjects.
- Wijngaarden et al (2000) EPRI-funded study of 138,905 U.S. electric utility workers found increased suicide mortality among electricians and line workers and reported a dose-response relationship with recent magnetic-field exposure, with particularly elevated risks among workers under age 50.

EMF can act systemically with other toxic exposures.

Numerous studies have reported synergistic effects when EMF is combined with other toxic exposures.

- Soffritti et al. (2016), published in the *International Journal of Radiation Biology*, found that lifelong exposure to a 50 Hz magnetic field combined with low-dose gamma radiation significantly increased the incidence of mammary tumors,

lymphomas/leukemias, and malignant heart schwannomas in rats.The authors conclude that," These results call for a re-evaluation of the safety of non-ionizing radiation."

- Rajkovic et al. (2010) published in *Archives of Environmental Contamination and Toxicology* reported that peripubertal male rats exposed to both the endocrine-disrupting herbicide atrazine and power-frequency EMF showed significant degranulation of cutaneous mast cells, with combined exposures producing stronger effects.
- Chen et al. (2021) published in *Ecotoxicology and Environmental Safety* reported that combined exposure to Di (2-ethylhexyl) phthalate (DEHP) and 50 Hz magnetic fields (MF) enhanced proliferation of human amniotic cells. The authors state, "Given that both MF and DEHP are ubiquitous environmental contaminants, the adverse effect of co-exposure at "safe levels" should not be underestimated."
- Ansarihadipour & Bayatiani (2016) in Iranian Red Crescent Medical Journal reported that lead in the presence of EMF exacerbated the oxidative damage to plasma proteins in human blood samples. "This result demonstrates that EMF and lead have synergistic effects that produce reactive oxygen species and promote chemical and conformational modifications in erythrocyte and plasma proteins."
- Moretti et al. (2005) published in *Toxicology Letters*, found that exposure to a 50 Hz magnetic field increased the DNA-damaging effects of two toxic benzene metabolites, hydroquinone and 1,2,4-benzenetriol, in human cells, suggesting ELF magnetic fields may enhance the effects of certain chemical carcinogens. "The possibility that 50 Hz (power frequency) MF might interfere with the genotoxic activity of xenobiotics has important implications, since human populations are likely to be exposed to a variety of genotoxic agents concomitantly with exposure to this type of physical agent."
- Ramazi et al. (2023) study published in *Scientific Reports* found that a 50 Hz ELF magnetic field acted synergistically with the chemotherapy drug doxorubicin, significantly increasing breast cancer cell death compared with the drug alone. The findings demonstrate that the synergistic effect of ELF magnetic fields may have beneficial therapeutic applications.

EMF has been found to impact animals and their habitat.

Studies on EMF, flora and fauna

Current scientific evidence exists that indicates the non-ionizing electromagnetic fields (EMFs) emitted by power lines and substations could impact the health of animals, including cattle, birds and bees.

A landmark three-part research review of non-ionizing EMF impacts on flora and fauna published in Reviews on Environmental Health citing more than 1,200 scientific references (Levitt et al. 2021a, Levitt et al. 2021b, Levitt et al. 2021c) found a broad range of impacts in all species studied including altered behavior, reproduction, endocrine disruption "at vanishingly low levels."

"Numerous studies across all frequencies and taxa indicate that current low-level anthropogenic EMF can have myriad adverse and synergistic effects, including on orientation and migration, food finding, reproduction, mating, nest and den building, territorial maintenance and defense, and on vitality, longevity and survivorship itself. Effects have been observed in mammals such as bats, cervids, cetaceans, and pinnipeds among others, and on birds, insects, amphibians, reptiles, microbes and many species of flora."
-Blake Levitt, Henry Lai and Albert Manville in
"Effects of non-ionizing electromagnetic fields on flora and fauna, Part 2 impacts: How species interact with natural and man-made EMF" *Reviews on Environmental Health*

EMF has been linked to cancers in animals

Brabant, Christian et al. (2024), a systematic review and meta-analysis on animal studies that studied ELF-MF and cancer incidence, published in *Progress in Biophysics and Molecular Biology* concluded that while ELF-MF do not affect the odds of lymphoma, brain cancer and breast cancer in rodents, it did increase the odds of developing leukemia in mice. Their "systematic review also suggests that ELF-MF can damage DNA in certain cell types like brain cells." The authors conclude that the carcinogenic effects could be limited to leukemia.

Notably Reif et al. (1995), published in the *American Journal of Epidemiology,* found that pet dogs living in homes with high or very high wire codes, a surrogate measure of magnetic field exposure from nearby power lines, had an increased risk of lymphoma, with dogs in the very highest wire code category having nearly a sevenfold increased risk compared with dogs living near buried or low-current power lines.) Minimal research has investigated the impact of power line EMF to dogs and pets.

Studies on high-voltage power lines, EMFs, and bees

Research over several decades has reported that the electromagnetic fields (EMFs) generated by high-voltage transmission lines can negatively affect pollinators, particularly honeybees, by interfering with navigation, foraging, learning, stress physiology, and pollination efficiency. As an example of the early research, Wellenstein 1973 documented how honey bee colonies beneath 110-kV and 220-kV transmission lines became significantly more irritable, with increased swarming behavior and altered colony performance compared with control colonies located 60–800 meters away. Greenberg et al (1981) found honeybee colonies exposed under a 765-kV, 60-Hz transmission line at 7 kV/m "show the following sequence of effects: 1) increased motor activity with transient increase in hive temperature; 2) abnormal propolization; 3) impaired hive weight gain; 4) queen loss and abnormal production of queen cells; 5) decreased sealed brood; and 6) poor winter survival."

Because honeybees rely on highly sensitive electrical, magnetic, and sensory cues to locate flowers and communicate within colonies, researchers have raised concerns that chronic

exposure to power line-associated EMFs and electric fields could contribute to pollinator decline.

- Thill et al. (2023), a major systematic review and meta-analysis research review on the research since 1980 on non-ionizing EMF and insects, published in *Reviews on Environmental Health* found "the vast majority of studies found effects, generally harmful ones." Studies document altered behavior and enzyme activity/metabolism, increased oxidative stress, DNA damage, and impaired reproductive capacity, memory and development.
- Molina-Montenegro et al. (2023), published in *Science Advances* found that the EMF exposure from high-voltage transmission towers increased stress-related gene expression, reduced honeybee flower visitation, impaired pollination efficiency, and even decreased seed production and plant community richness near the transmission lines.

"We propose that honeybees' exposure to EMF disturbs their foraging capabilities by altering their magnetic navigation, learning, decision-making mechanisms, flight, and foraging, thus impairing pollination activity…Our study provides strong evidence of detrimental effects of EMF on honeybee's visitation and plant reproduction and may contribute to explaining, at least in part, the global pollination crisis that risks the adequate production of many crops."
–"Electromagnetic fields disrupt the pollination service by honeybees"

- Levitt et al. 2021b details how bees may be reacting negatively to EMF "through muti-sensory mechanisms to numerous sources of anthropogenic multi-frequency [EMF] interference." The review also details research dating back to the 1970s showing that transmission line electric fields affected honey bees in wooden hives, prompting investigations by the U.S. Bonneville Power Administration and industry researchers. Those subsequent studies found that electric fields from powerlines could induce currents inside hives and lead to numerous effects, including decreased colony weight gains, increased irritability and mortality, abnormal production of queen cells, queen loss, decreased seal brood, and poor over-winter colony survival.
- A review by wildlife biologist Alfonso Balmori published in Science of the Total Environment entitled "Electromagnetic radiation as an emerging driver factor for the decline of insects" found "sufficient evidence" that electromagnetic radiation impacts insects and concludes that "electromagnetic radiation should be considered seriously as a complementary driver for the dramatic decline in insects, acting in synergy with agricultural intensification, pesticides, invasive species and climate change."
- Mallinson et al. (2025) published in *iScience* by found that anthropogenic electric fields comparable to those measured near high-voltage transmission lines significantly reduced honeybee floral landings. Alternating current (AC) electric fields reduced bee landings by 71%, while positive direct current (DC) fields reduced landings by 53%. They concluded that electric pollution from power infrastructure has the potential to disrupt plant–pollinator interactions and highlighted the need for further research on its ecological impacts.

- A series of studies by researchers at Wroclaw University Poland exposed bees to various EMF intensities reporting a range of impacts. Migdal et al (2020) published in Insects found the electric field exposure impacted the antioxidant system of the honeybee. Migdał P et al. (2021) published in *Animals* found behavioral disturbances may reduce the efficiency of bees as pollinators, which will translate into a decrease in the efficiency of crop production. Migdal et al (2021) published in *PLOS ONE* found the impairment of crucial metabolic cycles and alterations to the concentration of important non-enzymatic antioxidants which may indicate a disturbance in protein metabolism and increased muscle activity.
- Shepherd et al. (2019), published in PLOS ONE, found that short-term in honeybees exposure to powerline EMFs, at levels that could be encountered in bee hives placed under or near power lines, impacted learning and increased aggression levels.
- Shepherd et al. (2018), published in Scientific Reports found exposure to ELF EMFs near powerline conductors, affected honey bee olfactory learning, flight, foraging activity and feeding.

"The results suggest that 50 Hz ELF EMFs emitted from powerlines may represent a prominent environmental stressor for honey bees, with the potential to impact on their cognitive and motor abilities, which could in turn reduce their ability to pollinate crops."- Extremely Low Frequency Electromagnetic Fields impair the Cognitive and Motor Abilities of Honey Bees | Scientific Reports

Studies indicate EMFs may increase the harmful effects of pesticides and other environmental stressors on bees

Evidence suggests that EMFs may act as a co-stressor, amplifying the harmful effects of pesticides and other environmental stressors on honeybee health.

- Lupi et al. (2021) published in *Insects* monitored honeybee colonies in several experimental conditions for one year and found that combined multi-stress exposure of pesticides plus electromagnetic fields from a high-voltage transmission line caused the most severe biochemical, physiological, and behavioral alterations.
- Piechowicz et al. (2020), published in *Environmental Research*, found that exposure to EMFs changed how honey bees broke down and detoxified two pesticides and caused changes to proteins, DNA, RNA, and other important molecules in their bodies.

"In this study, the cumulative effect of chemical and electromagnetic field exposure (multi-stress conditions) showed the worst general health condition, considering colony survival, pathology emergence and behavioural anomalies such as abnormal honey storage and excess of drone brood deposition. For the number of queen changes and the queen mortality in the underbasket, double the rate occurred than in the control and even in the chemical-stress site."

-Combined Effects of Pesticides and Electromagnetic-Fields on Honeybees: Multi-Stress Exposure

Studies find magnetic fields can affect fish development and reproduction.

There has been little research directly examining fish living in streams or ponds beneath overhead transmission lines. However, a growing body of research has investigated whether the electromagnetic fields (EMFs) generated by underwater transmission cables affect fish and other aquatic organisms, demonstrating that some species can detect and respond to these fields.

- Formicki et al. (2021), published in the *International Journal of Molecular Sciences*, reviewed dozens of studies on the effects of magnetic fields on the early developmental stages of fish and concluded that magnetic fields can affect embryonic development, survival, embryo size, motor function, pigmentation, respiration, hatching success, orientation, sperm motility, egg activation, heart rate, and inner ear development.

- Guo et al. (2023), published in the *International Journal of Molecular Sciences*, found that developing zebrafish exposed to 50 Hz magnetic fields significantly reduced spontaneous movement, caused structural abnormalities in the brain, increased oxidative stress (reactive oxygen species, ROS), and altered expression of a gene essential for nerve cell communication.

EMF can Impact the Endocrine System: Implications for Agriculture, Especially Dairy Cows

Prolonged exposure to non-ionizing electromagnetic fields (EMFs) has been associated with changes in hormone regulation in both humans and animals. These effects are particularly important for livestock, where disruptions to hormone function may affect fertility, milk production, and overall herd health. While not all studies have found effects, numerous studies have reported impacts.

- Tojza et al. (2026), a review on endocrine impacts, published in *Applied Sciences,* concluded that animal studies consistently show EMF exposure can disrupt the endocrine system by altering stress hormones, suppressing melatonin release, affecting thyroid hormone activity, and impairing reproductive function, changes that may influence growth, metabolism and fertility.
- Kolbabová et al. (2015) published in *Scientific Reports* found that exposure to EMF magnetic fields altered melatonin production in young cattle calves in a season-dependent manner, with significantly reduced melatonin levels during the winter as compared to the summer where melatonin levels were increased.

- Stelletta et al. (2007), published in *Biomedical and Environmental Sciences*, found that dairy cows exposed to levels of EMF expected from 380 kV transmission lines had altered circadian rhythms and changes in immune system markers, indicating that power line EMF exposure can affect immune function and biological rhythms.
- Rodriguez et al. (2003), published in *Animal Reproduction Science*, found that exposure to 60 Hz electric and magnetic fields significantly altered the estrous cycle and prolonged the luteal phase in dairy cows, demonstrating that EMFs can affect the endocrine system and reproductive function.
- Burchard et al. (1998), published in Bioelectromagnetics, found that dairy cows exposed to 60 Hz electric and magnetic fields had significantly longer estrous cycles than during unexposed periods, indicating that EMF exposure altered normal reproductive cycling.

From Electric Transmission Lines Individual Rights vs Utility Rights of Public Domain By Donald Hillman, Ph.D., Professor Emeritus, Michigan State University January 10, 2005

"Burchard et al. reported in Bioelectromagnetics (2003): Sixteen nonpregnant lactating Holstein cows with 150 ± 40 days of lactation were confined to wooden metabolic crates in a E & MF chamber during the experiment with a 12:12 h light:dark cycle: Results were as follows:

1. Milk production decreased 5% from exposed cows compared to controls.
2.- Fat-corrected milk decreased 14%compared to controls- .
3. Milk fat decreased 16% compared to controls
4. Dry matter intake increased 5% compared to controls.

Physiological effects from Burchard et al. include:

1. Melatonin, a hormone produced in the Pineal gland in the brain, decreased in cows exposed to EMF.
2. Melatonin has strong oncostatic immunological, and antioxidant properties in the blood. It normally follows the pattern of light:dark nocturnal exposure.
3. Progesterone increased in lactating pregnant cows.
4. Length of estrus cycle increased 3 days.
5. Insulin-like growth factor (IGF-1) increased in blood.
6. Growth hormone was modified during part of the nocturnal cycle.
7. Macro and trace element changes in blood: Calcium, magnesium, iron, and copper were affected by EMF exposure.
8. Cerebrospinal fluid (CSF) changes in concentrations of Ca, P, Mg, Mn and Na occurred.
9. Quinolinic acid increased in CSF, tryptophan tended to increase in CSF.
10. CSF changes were consistent with weakening of bloodbrain barrier, according to the authors.

Effects on Immune System of Cows Exposed to Overhead Transmission Lines: Investigators in Italy, analyzed the blood cells and antigens of dairy cows housed 7 meters under a 380 kV transmission line. Cattle on farm A were exposed to 1.98 to 3.28 μT, whereas the values measured on the control farm B can be considered zero, except in brief periods (3 min 4 x per day) the measures were from 0.2 to 0.7 μT when

the automatic feeder was running. Results indicate that certain sub-populations of lymphocytes particularly CD4+/CD8 ratios indicate a depressing effect:on blood cells and immunity that maybe,-, specific for ELF-EMF electrical exposure. (Calogero et al., Effects of EMF on Circadian Rhythms and Distribution of Some Leucocyte Differentiation Antigens in Cows, University of Padua, Italy, International Veterinary Conference, Quebec 2004).

Marino et al., at LSU Medical Center, concluded that power frequency fields produce changes in the immune system that were both ieal and inconsistent, thus linear relationships should not always be expected while statistical method for chaos were most helpful. Serotonin, the most important neurotransmitter in the body; and neuroreceptors in the brain were modified by EMF in experiments at several universities."

Full article is here
https://interchange.puc.texas.gov/Documents/38597_875_676229.PDF

Studies have linked power line EMFs to behavioral effects in mammals.

- Iakovenko et al. (2025), published in *Animals*, found that high-voltage power lines significantly altered the magnetic orientation behavior of domestic dogs, suggesting that the alternating magnetic fields generated by power lines may interfere with dogs' magnetoreception and influence their natural orientation behavior. These findings build on earlier research by Hart et al. (2013), published in *Frontiers in Zoology*, which demonstrated that domestic dogs are sensitive to subtle variations in the Earth's magnetic field.

- Begall et al. (2008), published in the *Proceedings of the National Academy of Sciences (PNAS)*, found that cattle and deer preferentially aligned their bodies along the Earth's north-south magnetic axis while grazing or resting, providing evidence that large mammals can detect and respond to the Earth's magnetic field. Cattle naturally graze and rest facing a magnetic north-south direction. A subsequent study by Burda et al. (2009) published in the same journal found that the extremely low-frequency magnetic fields directly beneath high-voltage lines completely disrupt this internal compass, causing cows and deer to orient themselves in random directions.

"Body orientation of cattle and roe deer was random on pastures under or near power lines. Moreover, cattle exposed to various magnetic fields directly beneath or in the vicinity of power lines trending in various magnetic directions exhibited distinct patterns of alignment. The

disturbing effect of the ELFMFs on body alignment diminished with the distance from conductors. These findings constitute evidence for magnetic sensation in large mammals as well as evidence of an overt behavioral reaction to weak ELFMFs in vertebrates. The demonstrated reaction to weak ELFMFs implies effects at the cellular and molecular levels."

- Extremely low-frequency electromagnetic fields disrupt magnetic alignment of ruminants

Biological Effects of EMFs on Trees and Plants

A growing body of laboratory and field research indicates that EMF, even at levels below the limits of IEEE and ICNIRP, can have variable effects on plant growth, physiology, reproduction, and cellular processes.

Because of these biological effects, controlled EMF exposures are being investigated as potential agricultural tools to improve seed germination, plant growth, and crop productivity. However, these EMF applications involve carefully controlled field strengths, frequencies, and timing that are optimized for specific plant species. This research should not be interpreted to mean that the continuous, uncontrolled EMF produced by high-voltage transmission lines will have beneficial effects. Rather, this research confirms that the EMF generated by electrical grid infrastructure can affect plants and trees at levels created by electrical grid infrastructure.

- Levitt et al. (2021, 2021,2021) evaluated numerous studies on wildlife and plants, concluding that numerous plant species exhibit biological responses to both ELF and radiofrequency EMF at environmentally relevant exposure levels. The authors recommend recognizing anthropogenic EMFs as an environmental pollutant and developing environmental exposure standards to protect ecosystems.
- Kouzmanova et al. (2026) published in *Applied Sciences* reviewed the mechanisms by which electromagnetic fields influence plants and their potential applications in smart agriculture. They concluded that plants respond to EMF through well-established biological pathways, including changes in calcium signaling, reactive oxygen species (ROS), ion transport, enzyme activity, gene expression, and photosynthesis.
- Da Silva and Dobránszki (2016) published in *Protoplasma* found magnetic fields can modify seed germination and affect seedling growth and development in a wide range of plants, including field, fodder and industrial crops and cereals.
- Maffei (2014) reviewed evidence that plants perceive magnetic fields as environmental signals, with effects on calcium signaling, reactive oxygen species, gene expression, germination and stress responses.

Stray voltage, electrical disturbances, induction, and interference

Studies find stray voltage, ground current, harmonics and electrical disturbances can affect dairy cattle

The policies in place for electricity and health for livestock are inadequate according to several independent researchers.

Stray voltage, induction, ground current and other electrical disturbances associated with electrical power systems have long been recognized as agricultural concerns because they can affect livestock behavior, health, and milk production. Stray voltage occurs when electrical current travels onto objects like irrigation systems, fencing, pipelines, and other metal infrastructure creating unwanted electrical shocks. If a long metal fence or an ungrounded metal building roof runs parallel right beneath a high-voltage line, the air can "induce" a charge onto that metal.

On-site farm equipment and faults in the electrical system can also create stray voltage, and once identified, it can often be corrected.

- Hillman et al. (2013), published in *Science of the Total Environment,* analyzed electrical measurements and milk production data from 1,705 dairy cows on 12 farms in Wisconsin, Michigan, and Minnesota. The researchers found that electrical transients, harmonic distortion, and earth currents were associated with reduced milk production and altered animal behavior. They concluded that existing utility standards for actionable voltage were not sufficiently protective and recommended substantially lower limits urging the IEEE to address the effects of harmonic currents on human and animal health. **They concluded that the actionable level should be reduced to 10 mV (peak-to-peak), which is 140 times less than the current standard.**

  To date, IEEE standards have not incorporated these recommendations. Several states, including Wisconsin, Michigan, Idaho, and Minnesota, have adopted standardized stray-voltage investigation protocols for livestock. These are utility action thresholds, not health-based exposure limits, and they are not IEEE standards. In addition, Bloomberg has reported that data centers can contribute to harmonic distortion on the electric grid.

Minnesota Court of Appeals Affirms $9M Verdict for Stray Voltage
Randall Norman and Peggy Norman, Respondents, v. Crow Wing Cooperative Power and Light Company, Appellant.
The Normans operated a dairy farm in Pine River, Minnesota. Starting in 1994, their dairy herd began experiencing severe health and reproductive issues, causing a steep decline in milk production. In 2011, it was confirmed that the issue was caused by stray electrical voltage originating from the utility provider, Crow Wing Cooperative. The stray voltage used the cows' hooves as an unintended electrical pathway, causing chronic health problems and forcing the Normans to liquidate their herd in 2012. The Normans sued the cooperative for negligence and nuisance.

In Norman v. Crow Wing Cooperative Power and Light (No. A15-0983), the Minnesota Court of Appeals affirmed a $6.36 million judgment against the utility cooperative. The court upheld findings that the cooperative's electricity system directly caused the degradation and eventual loss of the Normans' dairy operation. You can read more about the case details here.

News Stories
Pine River Dairy Farmers Win Appeal Against Crow Wing Power Company - CBS Minnesota
Minnesota Court of Appeals Affirms $9M Verdict for Stray Voltage- National Trial Lawyers
Crow Wing Cooperative Power and Light Company, Appellant, vs. Great River Energy, et al., Respondents :: 2019 :: Minnesota Court of Appeals Decisions

While many reported stray-voltage problems result from faults in farm electrical systems or distribution lines rather than high-voltage transmission lines, some states and transmission projects require or recommend pre- and post-construction stray-voltage testing near livestock facilities because high-voltage power lines can potentially induce voltage or current in nearby conductive structures.
This is an area that warrants additional research, funded independently from the industry, particularly as new 500 and 765 kV transmission lines are proposed for data centers. Utilities often state that it is safe for livestock to graze and for agricultural equipment to operate beneath these lines within the right-of-way.

In addition, if a nearby lightning strike energizes the electrical system, dangerous voltages could be transferred to a fence. **This is why proper grounding, routine inspection, and electrical safety within and near transmission line rights-of-way is critical.** Most utilities have investigation protocols for contact voltage and stray voltage. These often specify when testing is required, how to measure contact voltage, and what mitigation is needed if elevated voltages are found. However, there is no single nationwide U.S. utility contact-voltage limit that all electric utilities must follow. Requirements for oversight vary by utility and state.

Utility companies generally inspect high-voltage lines and their right-of-way corridors 1 to 2 times per year, typically using helicopters, drones, or ground crews but they do not necessarily have a standard schedule to check every individual farm fence.

Since 1984, farmers have won substantial damages in stray-voltage cases, with awards ranging from $36,500 to as much as $14 million. In a 2017 Iowa case, *Burdick v. Interstate Power & Light Co.*, the Iowa Court of Appeals upheld a $500,000 jury award to a dairy farm after finding sufficient evidence to support damages caused by the utility's negligence.

"Even when the stray voltage current is at a low level, specifically anything above 0.5 volt, it can still be harmful to livestock. These currents put stress on the animals, which in turn lowers their immune systems, leading to a variety of issues. Dairy cows have shown to be more sensitive to stray voltage than any other livestock. Voltage has been shown to cause

decreased milk production, due to a lowered water intake and in turn a lowered feed intake. Farmers have also noted a range of issues relating to breeding and calving. Dairy farmers have even reported extremely sick cows, some of which have later died."
-Stray Voltage and Dairy Farms Can Lead to Large Damage Awards | Iowa State University, Center for Agricultural Law and Taxation

Transmission Lines Could Cause AC Interference with Buried Gas Pipelines

When high-voltage transmission lines run parallel to or cross buried steel pipelines, electromagnetic induction has the potential to produce AC voltages and currents on the pipeline. This can accelerate localized corrosion, interfere with cathodic protection systems, and create electrical safety hazards. If not properly evaluated and mitigated, AC-induced corrosion can compromise pipeline integrity, increasing the risk of leaks or, in rare cases, pipeline rupture if not properly evaluated and mitigated. Documented cases of AC-corrosion-related pipeline failures have been reported internationally, including in Canada, Germany, Australia, and the United States,
Because the risk depends on project-specific conditions, utilities conduct engineering studies to evaluate AC interference and determine whether mitigation measures are required.

A pipeline can experience significant induced voltages when it runs parallel to a high-voltage transmission line for long distances, even if the pipeline is tens or hundreds of feet away. Companies conduct project-specific electromagnetic interference studies rather than relying on a simple setback distance.

Concerns about this issue have already been raised for proposed 765 kV transmission projects in Texas that would cross major natural gas pipelines. Landowners have requested project-specific AC interference studies, disclosure of the anticipated mitigation measures, and evaluation of the associated costs *before the proposal moves forward.*

Resources

- Understanding and Mitigating the Threat of AC Induced Corrosion on Buried Pipelines
- Mitigation of inductive coupling effects on buried pipelines using gradient control conductors of overhead line configuration and hippopotamus optimization algorithm
- Modeling, analysis, and shielding of the electric field between extra-high-voltage AC transmission lines and oil pipelines

Transmission lines can impact biodiversity through their construction and operation

The systematic review "Power lines and impacts on biodiversity: A systematic review" by Biasotto & Kindel (2018) examined 206 scientific articles and 19 Environmental Impact studies finding 28 distinct biotic impacts, effects on plants, animals, populations, and ecological communities linked to transmission line construction and operation. They found that most impacts which originate during the construction phase (e.g., vegetation clearing, habitat alteration, soil disturbance), continue into the operational phase of the transmission line. Some of the most commonly reported impacts include:

- Changes in species abundance, distribution, and behavior.
- Bird mortality from collisions with wires.
- Bird and mammal mortality from electrocution.
- Habitat loss and fragmentation caused by right-of-way clearing:
- Increased access for invasive species.
- Altered predator–prey relationships.
- Changes in community composition and ecosystem functioning.

Clearing wide pathways for power lines removes trees and disrupts plant and animal habitats. This changes local microclimates and can increase the spread of invasive plant species in the newly cleared space.

A 2025 systematic review in *Oecologia* evaluated 815 studies on electrical infrastructure and animal biodiversity and concluded that "the majority of impacts towards animal biodiversity were reported to be negative," driven primarily by collision, electrocution, and habitat alteration. The authors found that powerlines can produce "significant effects on specific species," including major losses in grouse, ptarmigan, raptors, and the critically endangered great Indian bustard. While some species benefit from added nesting or perching habitat, the review cautioned that infrastructure can create a "winner and loser effect," helping some species while harming others.

The authors also stressed "significant knowledge gaps," particularly for insects, reptiles, amphibians, and ecosystem-level effects, and noted that EMF, noise, and UV impacts remain "largely unstudied" and specifically called for future research to expand into "EMF, noise, and UV radiation to provide a more comprehensive understanding of electrical infrastructure."

Importantly, they identified 18 publications reporting negative impacts from electromagnetic fields (EMF), yet found "no publications addressing the mitigation of electromagnetic fields (EMF)."

Impacts to Land and Water: Flooding and Contamination

The construction and physical installation of high-voltage transmission lines can also present risks to local water systems. Some examples:

- **Flood risk:** Establishing these massive power corridors requires clearing wide easements, stripping away trees and shrubs that naturally stabilize the landscape. Without this deep-root cover, exposed soil excavation areas are highly vulnerable to heavy rainfall, resulting in accelerated erosion and sediment-laden runoff. Furthermore, erecting massive steel towers alters natural drainage patterns. This all can spike flood risks.

- **Herbicide and Chemical Runoff:** Utilities generally use pesticides and herbicides, including Roundup (glyphosate) to prevent vegetation from growing into the live high-voltage cables. They also use other chemicals, all of which can leach into the soil or wash into streams during heavy rains, causing surface and groundwater contamination.

- **Zinc and heavy-metal contamination:** Transmission towers are commonly made of galvanized steel coated with zinc, which gradually corrodes and releases zinc into surrounding soils. Field studies have documented substantially elevated zinc concentrations in soils near galvanized electricity transmission towers, and other research has identified decades-old zinc contamination caused by runoff from galvanized power-line towers. Maintenance activities such as abrasive blasting can also deposit zinc and other metals around tower sites. This creates potential for runoff into nearby surface waters.

Studies document galvanized transmission towers can release zinc into surrounding soil, uptake by plants, and ecological effects including the development of zinc-tolerant plant populations.

- A 2003 field study in Environmental Toxicology and Chemistry sampled soils along transects approaching galvanized electricity transmission towers. Zinc increased from background concentrations of 25–82 mg/kg to 226–595 mg/kg near the pylons.
- A set of Swiss studies examined soils contaminated by runoff water from galvanized power-line towers. One study by Jacqat et al (2008) reported that corrosion of the zinc coating on 30- to 55-year-old towers had produced topsoil concentrations ranging from 1,322 to 30,090 mg/kg zinc. Their 2009 study analyzed 49 field soils that had been contaminated for decades by aqueous zinc carried in runoff from galvanized towers and found that once deposited in soil, zinc from galvanized tower runoff can persist, with its mobility and bioavailability strongly influenced by soil pH and contamination level.

- A 2011 European Journal of Soil Science study similarly examined soils affected by runoff from 17- to 74-year-old galvanized power-line towers, with zinc concentrations ranging from 251 to 30,090 mg/kg.

Studies show vegetation may accumulate higher levels of zinc if grown on contaminated soils.

> "Jones et al. (1988) found that corn plants and young corn plants (Zea mays) grown beneath and close to a galvanized electrical transmission tower had elevated concentrations of zinc due to corrosion of the zinc protective layer on the steel. Corn seedlings grown in a highly contaminated soil (1,425 µg zinc/g soil) a meter from the tower had zinc concentration in shoots and roots of 484±103 and 1,330±250 µg/g dry weight, respectively."- Agency for Toxic Substances and Disease Registry (ATSDR). 2005. Toxicological Profile for Zinc.
> U.S. Department of Health and Human Services, Public Health Service.

A series of studies by Al-Hiyaly and colleagues (1988, 1990, 1993) found elevated zinc beneath electricity pylons and the development of zinc-tolerant grass populations.

Elevated zinc can be toxic to aquatic organisms, especially in soft or otherwise sensitive waters, and the risk depends on runoff volume, dilution, pH, hardness, and water chemistry. Experts and government regulatory frameworks differ on what levels are acceptable.

Note on Lead contamination: Older high voltage power structures were historically coated with red-lead anti-corrosion paint. A 2013 study of contaminated soils near aged infrastructure found up to 700 mg/kg lead, with a substantial fraction present in extractable and soluble forms, indicating potential environmental mobility and bioavailability. The use of lead-based paint on utility infrastructure has since been phased out in the USA.

Power Lines And Birds: Collisions, EMFs and Shocks.

Due to collisions and electrocutions, power lines can kill hundreds of millions of birds each year. Collisions are the main risk for birds when it comes to high voltage power lines such as 500 and 765 kVs, but not electrocution. (See The Avian Power Line Interaction Committee's Suggested Practices for Avian Protection on Power Lines.) However, ultra-high-voltage environments affect large birds because the local ionized air from lines at 765 kV produces small shocks that generally deter birds from using the inner-lattice structure for building nests.

Further bird impacts are also due to the change in habitat caused by the removal of vegetation for the lines as rights-of-way, can be up to 100 m wide and cross natural habitats across long stretches of land fragmenting landscapes for all wildlife, including birds and mammals.

Pálsdóttir et al. (2022) published in the *International Journal of Avian Science* surveyed breeding birds along overhead power lines in Iceland and found that the combined breeding density of eight common ground-nesting bird species was lowest near power lines and increased with distance. The authors address numerous issues that could impact birds in their paper, such as how the lines are predator perches, and create visual disturbances, and noise but also that power lines generate an electromagnetic field, “which has been shown to affect avian behaviour, physiology and development” and they conclude that "power lines can influence the breeding density of ground-nesting bird species in their vicinity and that accounting for such effects when planning future infrastructure will be imperative."

Research has found that the electric and magnetic fields (EMFs) generated by high-voltage transmission lines can affect bird physiology, behavior, reproduction, and development. Examples of research on birds and EMF include:

- Fernie and Reynolds (2005), published in the *Journal of Toxicology and Environmental Health,* reviewing numerous field and laboratory studies on the effects of power line EMF on birds concluded that most studies reported EMF exposure altered bird behavior, reproductive success, growth and development, physiology, endocrinology, and oxidative stress.
- Mohamed et al. (2015), published in the *Pakistan Journal of Pharmaceutical Sciences*, exposed fertilized chicken eggs to magnetic fields at levels below IEEE limits before incubation. The researchers found that the exposure altered hemoglobin conductivity and reduced red blood cell membrane mobility in newly hatched chicks, indicating measurable changes in blood biophysics.
- Roda et al. (2011), published in *Histology and Histopathology,* exposed fertilized chick embryos throughout incubation to pulsed magnetic fields at levels below IEEE limits and found delayed early embryonic development, reduced growth at hatching, with significantly lower body weight, altered brain biology and reduced glycosaminoglycan expression in brain tissue, suggesting disruption of molecules important for normal brain development and organ formation. The authors concluded, "These results suggest that pulsed magnetic fields may be able to hinder normal embryonic development in vivo and to alter normal neural function."
- Fernie and Bird (2001) published in *Environmental Research* found that EMF exposure suppressed melatonin, altered immune function, reduced blood proteins, hematocrit, and carotenoid levels, and increased evidence of oxidative stress.
- Fernie et al. (1999) published in *Environmental Health Perspectives* found that EMF exposure to American Kestrels altered plasma melatonin levels in adult males, suppressed melatonin in fledglings following long-term parental exposure, advanced molting in males, and could affect migration, metabolism, and development.
- Fernie et al. (2000) published in *Physiological and Biochemical Zoology* found EMF exposure affected reproductive success of kestrels, increasing fertility, egg size, embryonic development, and fledging success but reducing hatching success.

In addition to power lines, data-center development can create several established threats to birds. Large campuses can replace or fragment habitat and introduce substantial nighttime lighting. Peer-reviewed research has shown that artificial light can attract and disorient migrating birds and substantially increase fatal building collisions, while overhead power lines are a well-established source of collision and electrocution mortality.

A 2017 Proceedings of the National Academies of Sciences study found that powerful artificial nighttime lighting attracted and disoriented migrating birds, causing them to cluster, circle, slow their flight and vocalize more, with an estimated 1.1 million birds affected over seven nights of observation.

Protecting Birds Through Better Transmission Line Design and Siting

Many Countries Require Bird-Safe Power Line Designs—The U.S. Does Not

According to the UN Environment Programme power lines constitute one of the major causes of unnatural death for birds and “the most effective measure to avoid both electrocution and collision is underground cabling, which has already been done in countries such as the Netherlands and in certain parts of Belgium, the United Kingdom, Norway, Denmark and Germany.”

The UN recommended measures include

- The most effective measure to eliminate the possibility of both electrocution and collision is underground cabling. This has already been done in the Netherlands and in certain critical locations in Belgium, the United Kingdom, Norway, Denmark and Germany. This method is very costly and therefore not feasible for the whole AfricanEurasian region.
- Another obvious way in which to prevent bird electrocutions and collisions is minimizing the construction of new power lines, through efficient network planning and dispersed power generators.
- Routing new power lines away from areas that are home to, or attract, bird species that are known to be susceptible to electrocution and collision, also taking into account landscape and vegetation features.
- Designing the location, route and direction of power lines on the basis of national zoning maps, avoiding, where possible, the construction in habitats of conservation importance, such as important bird areas, protected areas, Ramsar sites and other

critical sites as identified by the Critical Site Network (CSN) Tool: http://csntool.wingsoverwetlands.org/csn/default.html

- The guidelines include many other technical measures for both electrocution and collision. These include insulation measures, line design or configuration, perch management techniques and a range of power line marking devices including spheres, swinging plates, bird flappers and others which make lines more visible to birds.
- The review also includes a summary assessment of the efficiency of such marking devices, sighting ongoing research in different countries, with some concluding that wire marking reduced bird mortality by 50-80%.

Text from "UN Wildlife Meeting Pushes to Make Power Lines Safer for Birds "

As an example, Germany has incorporated bird protection into its Federal Nature Conservation Act by requiring utilities to protect birds from electrocution on overhead power lines. The law requires newly constructed medium-voltage power lines to use bird-safe designs and mandated the retrofitting of existing hazardous poles where birds are at risk.

The United States Lacks a Comprehensive Federal Framework to Protect Birds from Power Lines

Requiring utilities to incorporate proven mitigation measures during the design, construction, and maintenance of transmission infrastructure can substantially reduce wildlife mortality.

No Federal Requirements to Prevent Harm: The United States lacks a unified, federal design code mandating bird-safe power lines and instead, the federal framework relies on the Migratory Bird Treaty Act (MBTA) and the Bald and Golden Eagle Protection Act (BGEPA), which penalize utilities for the unpermitted killing of protected species. However this is a reactive approach forcing action only after harm has occurred. As an example, under the Reactive Retrofit Strategy mandated by 50 CFR § 22.260 and the U.S. Fish and Wildlife Service (USFWS) Power Line General Permit, when an eagle is killed or injured on a power line, the utility must retrofit the lethal pole plus enough nearby structures to equal a total of 13 poles or a half-mile segment of line, whichever is less.

A Lack of Data on Actual Bird Electrocution: Thus, the scale of national bird mortality from power lines is drastically underestimated. There is no government surveillance program for bird and other wildlife fatalities, and the framework relies almost entirely on utility self-reporting. Because millions of miles of power lines cross remote areas where scavengers can quickly remove carcasses, most bird electrocutions are not documented. The widespread under-reporting masks the true scale of bird mortality and a legacy of hazardous, non-compliant poles exists.

Voluntary Industry Guidelines: Many companies adopt the guidance documents of the Avian Power Line Interaction Committee (APLIC) which includes dozens of electric utility companies, however compliance is voluntary and uneven. While many utilities have adopted Avian Protection Plans and proactively install bird-safe equipment and retrofit hazardous structures, others do little or no mitigation unless bird deaths trigger enforcement actions.

In short, there is little regulatory oversight to ensure utilities follow these recommendations, no nationwide compliance program, and no federal requirement that hazardous poles be systematically identified and retrofitted. The patchwork of protection varies considerably among utilities and states. Uniform national design standards requiring bird-safe transmission line design, oversight and compliance are needed.

Publications on Bird Electrocutions and Effective Mitigation Strategies

Reports

Protecting birds on powerlines: a practical guide on the risks to birds from electricity transmission facilities and how to minimise any such adverse effects. On behalf of NABU - German Society for Nature Conservation, Registered Charity and BirdLife Partner Germany

Ferrer, M., Florencio, C., Muriel, R., Morandini, V., & García-Macía, J. (2026). How to prioritize measures to reduce the electrocutions of birds in distribution power line networks. Global Ecology and Conservation, 69, e04318.

International Finance Corporation & European Bank for Reconstruction and Development. (2026). Preventing Electrocution Risks for Birds on Distribution Lines: Tip Sheet. International Finance Corporation

Biasotto, L. D., Moreira, F., Bencke, G. A., & Ascensão, F. (2022). Risk of bird electrocution in power lines: A framework for prioritizing species and areas for conservation and impact mitigation. Animal Conservation, 25(2), 285–296. doi.org

Ferrer, M., Morandini, V., Baumbusch, R., Muriel, R., De Lucas, M., & Calabuig, C. (2020). Efficacy of different types of “bird flight diverter” in reducing bird mortality due to collision with transmission power lines. Global Ecology and Conservation, 23, e01130.

Dixon, A., Rahman, M. L., Galtbalt, B., Gunga, A., Sugarsaikhan, B., & Batbayar, N. (2017). Avian electrocution rates associated with density of active small mammal holes and power-pole mitigation: Implications for the conservation of Threatened raptors in Mongolia. Journal for Nature Conservation, 36, 14–19. https://doi.org/10.1016/j.jnc.2017.01.001.

Bernardino, J., Bevanger, K., Barrientos, R., Dwyer, J. F., Marques, A. T., Martins, R. C., Shaw, J. M., Silva, J. P., & Moreira, F. (2018). Bird collisions with power lines: State of the art and priority areas for research. Biological Conservation, 222, 1–13.

Manville, A. M., II. (2005). Bird Strikes and Electrocutions at Power Lines, Communication Towers, and Wind Turbines: State of the Art and State of the Science – Next Steps Toward Mitigation In C. J. Ralph & T. D. Rich (Eds.), Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference (March 20–24, 2002, Asilomar, California) (Vol. 2, General Technical Report PSW-GTR-191, pp. 1051–1064). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Tintó, Albert; Real, Joan; Manyosa, Santi. "Predicting and correcting electrocution of birds in Mediterranean areas". Journal of Wildlife Management, 2010, 74(8): 1852-1862.

Papers on mitigating electrocution risk to birds.

- Mayrose et al. (2024), published in *Ornithological Applications,* found that insulating just 4% of power pylons identified as the highest-risk structures could reduce Bonelli's Eagle electrocutions by approximately 80%.
- Purevdorj et al. (2025), published in the Journal of Raptor Research, documented the widespread high electrocution of Steppe Eagles and Golden Eagles on Mongolia's power network. While the Mongolian government amended the national standard in 2021 to include bird safety, "compliance needs to be enforced as dangerous lines continue to be constructed." The authors recommended insulating hazardous poles, installing bird-safe perch deterrents, and prioritizing retrofits in high-risk areas to reduce raptor mortality.
- Kolnegari et al. (2025), published by *Cambridge University Press* documented electrocutions of mammals, reptiles, amphibians, and invertebrates across Iran's electrical network and found that most incidents occurred on properly functioning equipment whose design failed to account for wildlife contact. The authors recommend mitigation measures insulating energized components, redesigning hazardous equipment, and retrofitting existing infrastructure to protect wildlife while also reducing power outages and fire ignitions.

High-Voltage Transmission Lines Emit Corona Discharge, Audible Noise, and Ozone

High-voltage transmission lines can produce corona discharge, a phenomenon in which the intense electric field surrounding energized conductors ionizes the surrounding air. The result is

visible light, crackling and hissing sounds, ozone, and other reactive gases, while also creating radio interference.

UV: When high-voltage power lines corona discharge, they produce continuous, popping flashes of ultraviolet (UV) light that are invisible to humans but reported to be highly disruptive to wildlife. Many birds and mammals have UV vision. Tyler et al. (2014), *Conservation Biolog*y, reported that mammals and ground-nesting birds may avoid habitat for kilometers around high-voltage power lines, in some cases for decades, and visible-to-wildlife ultraviolet corona discharges may contribute to this behavior.

According to a PBS NOVA article "Power Lines Look Like Terrifying Bursts of Light to Animals," this visual pollution forces large mammals and birds to avoid transmission corridors by up to 2 miles. The article featured a study published earlier this year in the *Proceedings of the Royal Society B* whereby scientists analyzed the eyeballs of 38 different mammalian species. "What they found suggests that most mammals can, in fact, see UV light—including dogs, cats, ferrets, and reindeer."

Dr Nicolas Tyler, an ecologist at UIT The Arctic University of Norway stated, "The loss and fragmentation of habitat by infrastructure is the principal global threat to biodiversity – it is absolutely major. Roads have always got particular attention but this will push power lines right up the list of offenders."

While birds frequently perch on neighborhood power lines, they often avoid ultra-high-voltage transmission lines because the intense corona discharge is unique to high-voltage systems.

Noise: Corona discharge is responsible for the crackling, buzzing, and/or humming noise often heard near transmission lines, particularly during damp, foggy, snowy or rainy weather. (Moisture increases electrical activity.) Because transmission-line noise contains low-frequency hum and broadband corona noise, A-weighted sound meters alone may not fully characterize what people experience. These meters can underestimate the low-frequency hum and high-frequency corona noise. Frequency-spectrum analysis and C- or Z-weighted measurements can provide a more complete assessment of transmission-line noise, particularly under wet-weather conditions when corona discharge is greatest.

> Zhang et al. (2025), published in *Measurement,* conducted two years of monitoring at a 750-kV transmission line and found that the characteristic audible hum from high-voltage lines is most pronounced during rainy and snowy weather, when corona discharge intensifies, emphasizing the importance of accounting for weather when assessing transmission line noise.

Substations and Corona: Corona Noise vs. Transformer Hum

If you stand near an electrical substation, you will hear a distinct acoustic mix of two different sound phenomena: the high-frequency sizzling of corona discharge and the constant,

low-frequency hum of transformers. Unlike transmission lines where corona emits continuously along conductors, substation corona is localized to specific points of high electrical stress such as sharp edges, bolts, and bushings. There is also a transformer hum, which is a rhythmic, low-frequency buzz, typically at 120 Hz, aused by magnetostriction, which is the physical expansion and contraction of the transformer's magnetic core. While corona noise fluctuates with the weather and contains sharp, high-frequency bursts, transformer hum persists 24/7 regardless of atmospheric conditions, meaning a comprehensive noise assessment requires advanced frequency analysis to capture both sounds accurately.

Ozone: Corona discharge produces ozone (O_3) and nitrogen oxides (NO_x) through ionization of the air.

Interference: Corona discharge can be a source of higher current harmonics, creating "electromagnetic noise" across a wide range of frequencies, interfering with technologies like AM radios, emergency dispatch signals, and even wireless internet and other household technical systems.

Utilities and engineering organizations recognize corona discharge as an issue and transmission line designs often seek to minimize, but cannot completely eliminate, its occurrence.

High-voltage transmission lines and substations can pose a fire risk.

While wildfires can have multiple causes, utility equipment failures and inadequate maintenance have been responsible for numerous transmission line and substation fires.

The California Fire Local 2881 Firefighters have opposed the SDG&E Golden Pacific Powerlink Project stating:

“The proposed transmission line would introduce significant new electrical infrastructure into some of Southern California's most wildfire prone terrain. California has learned hard lessons about the risks associated with overhead transmission systems during extreme fire weather. We should not be creating additional ignition risks in communities that already face the threat of catastrophic wildfire.”

In 2024, the Texas House Investigative Committee on the Panhandle Wildfires Report concluded that the largest and most destructive fires were caused by electric power poles and lines that had not been adequately maintained or replaced by a utility provider and an oil and gas operator. The report found that aging and inadequately maintained utility poles were a significant ignition source and noted that, between 2000 and 2024, power lines caused more than 1,300 Panhandle fires that burned over 1.4 million acres.

Importantly, during an electrical grid (transmission line or substation) fire, firefighters often cannot directly attack the fire until the utility has de-energized the equipment because of the risk

of electrocution. Instead, firefighters are forced to focus on containing the fire and protecting nearby homes and vegetation while waiting for utility crews to disconnect power.

Examples of fires related to the electrical grid :

- **Camp Fire (California, 2018):** Ignited by PG&E transmission equipment, resulting in 85 deaths and the destruction of Paradise, California. According to court documents,
- PG&E repeatedly ignored warnings about its aging power lines and faulty maintenance, and failed to follow state regulations showing "a callous disregard" for life and property.
- **Dixie Fire (California, 2021)**: California investigators concluded PG&E equipment caused the fire, and violated state requirements in one of the largest wildfires in California history.
- **Maui Fire (Hawaii, 2023):** Ongoing litigation alleges Hawaiian Electric power lines contributed to the fire.Hawaiian Electric Industries reached a $47.75 million settlement with shareholders who claimed the company did not take appropriate action to reduce the risk that its utility poles could trigger wildfires.
- **Los Angeles fires (California, 2025):** Southern California Edison acknowledged its equipment may have been involved in the Hurst Fire. Investigators concluded that The Eaton fire was caused by electrical arcing on the utility's out-of-service tower. "When bare, uninsulated wires touch or come close together it can cause arcing, which is when electricity jumps through the air, producing sparks."
- **Smokehouse Creek Fire (Texas, 2024)**: The largest wildfire in Texas history burned over 1 million acres. The Texas Attorney General filed an injunction against Xcel Energy (Southwestern Public Service Company), accusing the utility of negligence regarding the upkeep of aging utility poles.
- **Kincade Fire (California, 2019):** Ignited by a broken jumper cable on a PG&E high-voltage transmission tower. State regulators fined PG&E $125 million after investigations revealed the utility failed to properly decommission or maintain the obsolete transmission equipment that triggered the blaze, which burned over 77,000 acres and forced the evacuation of nearly 200,000 people.
- **Fairview Fire (California, 2022):** Triggered when a drooping Southern California Edison (SCE) overhead line in Hemet swayed and made direct contact with a communications messenger wire, throwing hot electrical sparks into dry grass. The disaster resulted in two deaths, burned over 28,000 acres, and prompted a $37 million federal lawsuit accusing the utility company of negligence regarding line tension upkeep and vegetation management.
- **Labor Day Wildfires (Oregon & California, 2020):** Fierce winds downed power lines across the Pacific Northwest. In February 2026, PacifiCorp agreed to a $575 million settlement with the U.S. government to cover firefighting costs and public land restoration, adding to a rolling total of over $2.2 billion in settlements negotiated with nearly 90% of individual claimants who accused the company of negligence.
- **Marshall Fire (Colorado, 2021):** Investigators concluded that uninsulated, sagging power lines operated by Xcel Energy slapped together during a high-wind storm, producing hot aluminum particles that ignited dry grass. It became the most destructive wildfire in Colorado history, destroying over 1,000 homes in Boulder County and causing

upwards of $2 billion in damages. In September 2025, Xcel Energy agreed to a $640 million settlement to resolve the massive consolidated victim lawsuits over utility infrastructure failures.

- **Thomas Fire (2017):** Ignited when two Southern California Edison (SCE) power lines slapped together during high winds. SCE faced massive litigation, eventually leading to a multi-billion dollar settlement framework to resolve claims related to the utility's infrastructure shortcomings and failure to clear vegetation around its lines.

"This injunction requiring Xcel to inspect and replace its dilapidated and damaged utility poles is critical for protecting the safety and livelihood of Texans," said Attorney General Paxton. "This win is the first part of holding Xcel accountable and ensuring preventative measures are being taken as the case continues to move forward. Xcel has made the right decision in working with my office and ultimately agreeing to take these critical first steps. The Smokehouse Creek Fire caused devastation throughout the Texas Panhandle, and I will continue to fight to ensure that justice is served and that wildfires will no longer be sparked by the negligence of a utility provider."- Attorney General Paxton Secures Injunction Against Electric Company that Caused the Devastating Smokehouse Creek Fire

Examples of substation fires include:

- **Heathrow Airport Substation Fire (United Kingdom, 2025):** The official investigation concluded that the fire was a preventable fault directly caused by National Grid's failure to maintain the infrastructure.
- **Maida Vale, London (2025):** A high-voltage electrical event caused the fire.
- **San Francisco Mission Substation Fire (December 2025):** PG&E was found to have ignored critical warning signs and regional audits revealed a year full of safety and maintenance violations across their local substations, including unaddressed oil leaks, loose wires, and broken cooling fans.

Excerpt from "Allocating Utility Wildfire Costs:Options and Issues for Consideration" by The California Legislative Analyst's Office.

Utilities Start a Small Portion of Fires, but They Are Often the Largest and Most Damaging

- Only about 10 percent of fires are started by utility equipment, and many of those fires result in little or no property damage.
- However, some of the most damaging fires are started by utility equipment. For example, utility powerlines caused at least 8 of the 20 most destructive fires (40 percent) in California's history. Seven of these utility-caused fires occurred since 2007, and six have occurred since 2015.
- Wildfires caused by powerlines can be particularly damaging, in part, because some of the factors that cause utility ignitions—such as high winds damaging electrical lines—also contribute to a rapid spread of fire that is difficult to control. For example, according to the California Department of Forestry and Fire Protection (CalFire)

investigations, Pacific Gas and Electric (PG&E) equipment started the 2018 Camp Fire in Paradise, which destroyed nearly 19,000 structures and killed 86 people. PG&E estimates that it could be liable for up to $15 billion in damages from the fire.

Further, birds electrocuted on power lines have ignited wildfires after falling into dry vegetation, with documented incidents reported in the United States, Spain, Iran, Australia.

Every new transmission corridor and substation introduces another potential ignition source into the landscape. Fire hazards associated should be considered alongside public health, environmental, and economic impacts during project approval and siting.

The US Lacks A Regulatory Framework To Protect Public Health.

Key Deficiencies in the U.S. Regulatory Framework

There is essentially no federal regulatory framework to address health impacts on non-ionizing EMF emitted by high-voltage transmission lines and substations. The United States does not have health-based federal safety standards, as the EPA was defunded from its EMF and health activities decades ago. This is only one of many regulatory deficiencies. Existing federal and state oversight also fails to adequately address numerous public health, environmental, monitoring, disclosure, and risk assessment issues associated with high-voltage transmission lines and substations.

Table 1 lists key regulatory deficiencies at the federal level.

Table 1: US Federal Regulatory Framework for Nonionizing EMF and Public Health Protection: Assumptions v. Reality

Assumed Element	Reality
Federal safety standards were developed to protect human health.	❌No federal safety limits for magnetic or electric field power frequency EMF. EPA was defunded from bioeffect research in the mid 90s.
Agencies with health and environmental expertise review the current science to ensure safety for the public.	❌No federal agencies have shown any review of the science on EMF for decades.

Agencies with wildlife and agriculture expertise have reviewed science to ensure safety for livestock, agriculture and wildlife.	❌No comprehensive federal review to determine whether long-term EMF exposure is safe for wildlife, livestock, or agriculture.
Industry IEEE and ICNIRP limits, used by the utility companies, protect against long term health effects like cancer.	❌IEEE limits are designed only to protect against nerve stimulation from short term exposure
Industry IEEE limits protect people with medical issues, including those who have pacemakers or other implanted devices.	❌IEEE explicitly states its standards are not intended to apply to patients under medical care and may not be protective for people using medical devices or implants.
Robust research by health and environmental agencies is always investigating EMF impacts to health and environment.	❌ No current research activities are being conducted by any federal agency.
Premarket safety testing for EMF emitted by high voltage transmission lines and substations.	❌ Never performed. When new higher power transmission lines are proposed, there is no requirement to test for health effects.
Requirement to model or disclose expected magnetic or electric field levels before construction.	❌ No requirements to model, measure, or disclose EMF levels. Such requirements exist only in certain states or as conditions of individual permitting processes.
Nationwide EMF level measuring and monitoring Post-market surveillance to ensure utilities are maintaining EMF levels they presented in the application process.	❌ No national program to measure and monitor EMF levels nationwide. Defunded in the 90s. ❌ No oversight. Utilities do not have yearly audits to show compliance. It's the honor system.
Post-market medical and environmental surveillance to gather data on health effects.	❌No reporting system. No surveillance system. No ability to analyze data as it is not collected.
Oversight and enforcement for compliance of network infrastructure	❌ No federal program auditing sites.
No setbacks for schools or safeguards and risk reduction policies for vulnerable groups.	❌ No measures to reduce exposure to children and the medically vulnerable. No increased oversight for exposure at schools and daycare.
Transparency regarding EMF exposures from equipment and in nearby homes.	❌ No requirement that EMF from grid equipment be publicly posted. No online maps with permit information or EMF level report. Companies do not have to model EMF in your home if you are near a power line.

Occupational health EMF protection program	❌ No robust EMF occupational health program exists to characterize worker EMF exposures and ensure protection. Activities by occupational health agencies were dismantled years ago.

Countries That Have Implemented Measures To Protect Public Health.

In contrast to the U.S., several countries have adopted exposure limits, precautionary siting an planning policies, target levels of investigations or other measures to reduce EMF exposure from power lines and substations based in part on research linking long-term exposure to elevated magnetic fields with an increased risk of childhood leukemia. As detailed in Table 2, the focus is generally on mitigating exposure in homes, schools, childcare facilities, hospitals, and other sensitive areas. Many of these countries also conduct national EMF monitoring programs and have regulatory oversight and compliance mechanisms to assess, track, and manage EMF exposure levels.

Country	Public Health Measures and/or Recommendations Includes legally binding exposure limits,planning objectives, and investigation/action levels
The Netherlands	• Since 2005, policies have been in place to reduce EMF in homes, schools, and kindergartens. The government recommended that local authorities maintain a distance between high voltage power lines and homes, schools, kindergartens, daycares and nurseries), so that children are not exposed to levels higher than 4 mG • In 2013, houses under 380–220 kV lines were bought out due to elevated exposure. • In 2023, based on a scientific literature review and recommendations of the Health Council, the government issued an updated and expanded policy to prevent new situations where people stay for a long time in the area near overhead power lines, substations and electrical grid equipment where the magnetic field exceeds 4 mG (annual average).
Belgium	• Flanders recommends new power lines should be avoided near schools and childcare centers, and exposure over homes should be minimized. Year-averaged exposure near new schools and childcare centers should not exceed 4 mG. • In Brussels, transformers near areas where children under 15 are must maintain a 24-hour average below 4 mG.
Germany	• A 2013 Ordinance requires all feasible measures to minimize EMF exposure for transmission lines, substations and railways. • High voltage transmission lines cannot be erected over buildings intended for long-term human occupancy. • The Federal Office for Radiation Protection (BfS) recommends precautionary measures because “In addition to the established health effects, there are scientific indications for health risks at low field

	strengths." and they recommend that "The population should be informed about the known and suspected effects of the fields and about the field intensities of the relevant field sources such as high-voltage lines or electrical appliances."
Israel	• The maximum permissible ELF-EMF exposure in schools and residences is 4 mG per recommendations of the Ministry of Environment and the Ministry of Health. • Ministries recommend minimizing long-term exposures, particularly for schools and residences.
Denmark	• Utilities must measure magnetic fields at new installations; annual averages should not exceed 4 mG. • No kindergartens or new buildings may be built near high-voltage lines.
France	• Ministerial guidance discourages new hospitals, maternity wards, and childcare facilities near power lines, cables, and transformers where fields exceed 1 μT. • The grid operator must monitor EMF emissions near power lines, and citizens can request measurements via local authorities.
French Polynesia	• The government-run public awareness campaign advises maintaining at least 1–1.5 meters from induction stoves and other EMF-generating appliances.
Slovenia	• ELF limits are set at 10% of the EU reference value for new or modified installations near residences, schools, kindergartens, hospitals, playgrounds, parks, and public buildings.
Switzerland	• The Non-Ionizing Radiation Protection Act establishes precautionary EMF exposure limits for new installations at 1 μT (10 mG) called an installation limit value. The country also measures, monitors, and reports EMF levels for transmission lines and substations.
Croatia	• Reduced ELF-EMF limits apply to sensitive areas, including homes, offices, schools, playgrounds, kindergartens, maternity wards, hospitals, and care facilities.
Luxembourg	• Ministerial recommendation exposure limit of 4 mG for vulnerable populations like pregnant women. • Ministerial recommendation prohibits new living spaces close to high voltage lines.
Norway	• A 0.4 μT "investigation level" applies to new homes, schools, kindergartens, and power lines; if exceeded, exposure-reduction measures are evaluated and implemented if reasonable.

Italy	• The 2017 Environment Ministry Decree recommends minimizing indoor ELF-EMF exposure; a precautionary "attention value" applies to 24-hour median exposure in homes, schools, playgrounds, and other spaces where people spend over 4 hours. • Three regions—Veneto, Emilia-Romagna, and Tuscany—enforced strict "quality objective" guidelines for new power line installations near homes and schools with a magnetic field limit of 2 mG.
Liechtenstein	• Has an installation reference value of 10 mG for places with sensible use and/or new installations not to be exceeded more than 1.5 times on a maximum of five days a year.
Toronto, Canada	• In 2008, the Toronto city council adopted a prudent avoidance policy to minimise EMF exposure, particularly for young children. Any recreation or parkland, residential, school or day nurseries newly planned or amended, which are adjacent to power line corridors, must adopt low or no cost measures to minimize exposures to electromagnetic fields. Furthermore, a health impact assessment is required to minimise any increase to yearly average exposures when new or upgraded high-voltage transmission lines are proposed within the city.
United Kingdom	• The government promotes a precautionary policy to reduce EMF including optimum phasing for high-voltage overhead power lines, a series of engineering measures designed to reduce net currents, and encourages substations be sited away from homes. • For low-voltage distribution networks (132 kV and below), the precautionary best practice measures to reduce EMF are set out in Engineering Recommendation G92 published by the Energy Networks Association.
Finland	• The radiation authority STUK advises avoiding permanent residences where magnetic flux density continuously exceeds ~0.4 μT. • Recommendation to keep electric and magnetic fields near humans as low as possible.
Sweden	The Swedish Radiation Safety Authority recommends in Magnetic fields - Strålsäkerhetsmyndigheten: "Recommendations: Due to the concern over a link between weak, low-frequency magnetic fields and the incidence of childhood leukaemia, the Swedish Radiation Safety Authority issues the following recommendations in connection with social planning and building projects: • Work towards the design or location of new power lines and electrical installations so as to limit exposure to magnetic fields • Avoid locating new housing, schools and pre-schools in close proximity to electrical installations generating elevated magnetic fields • Work towards limiting magnetic fields that deviate substantially from what can be deemed normal in home, school, pre-school and occupational environments."

	Swedish municipal planning policy, if an annual average field is calculated to exceed 4mG near homes or schools, they must legally investigate whether it is economically and technically viable to reduce it.

US State Power-Frequency EMF Policies and Permitting Requirements

Table 3 summarizes U.S. state policies related to power-frequency magnetic fields (MFs), health-based setbacks, right-of-way distances, and other EMF-related requirements for high-voltage transmission lines. It is not intended to be a comprehensive review of all state utility regulations or transmission line permitting requirements. Rather, it highlights the limited number of states that have adopted policies specifically addressing magnetic fields, public health, or separation distances, illustrating the overall lack of consistent health-based protections across the United States.

This document provides examples and does not reflect all policies. As a living document, it is updated regularly. While every effort has been made to ensure accuracy, the information is not guaranteed.Please send an email to Theodora@ehsciences.org.

State	Location	Electric Field (kV/m)	Magnetic Field (mG)
California[1]			

[1] CPUC EMF Design Guidelines for Electrical Facilities; PUC Actions Regarding EMFs

New schools must be at least 100 ft (50–133 kV), 150 ft (220–230 kV), and 350 ft (500–550 kV) from transmission line easements.
CPUC requires utilities to implement "no-cost and low-cost" EMF mitigation measures and to create a Field Management Plan on how they will reduce EMF exposure for new projects. No limits for electric and magnetic fields.[2]

Connecticut[3]

The Connecticut Siting Council must establish a project-specific buffer zone that considers "residential areas, private or public schools, licensed childcare centers, licensed youth camps or public playgrounds adjacent to the proposed route of the overhead portions and the level of the voltage of the overhead portions and any existing overhead transmission lines on the proposed route. Overhead transmission lines (345 kV or greater) adjacent to residential areas, private/public schools, childcare facilities, youth camps or playgrounds, are restricted unless the applicant can demonstrate that undergrounding will be technically infeasible or may result in an unreasonable economic burden on the ratepayers of the state. EMF measurements and EMF mitigation to satisfy the Council's Best Management Practices are required.

Hawaii

1998 The Department of Health, in response to continuing but inconclusive scientific investigation concerning electric and magnetic fields (EMF) from low-frequency power sources, recommends a "prudent avoidance" policy.[4]

Florida[5]	Above 500 kV	Within right-of-way	15	NA
		Edge of right-of-way	2	250
	(230-500 kV)	Within right-of-way	10	NA
		Edge of right-of-way	2	200[6]
	(230 kV or less)	Within right-of-way	8	NA
		Edge of right-of-way	2	150

Florida Building Code: buildings, play areas, and common-use areas at schools cannot be located within a high-voltage transmission line ROW.[7]

Iowa

Iowa Code Chapter 478 Section 478.20 states that no transmission line of 69 kV or more can be constructed within 100 feet of any dwelling house or building without a mutual agreement, unless it runs along a public highway or railway right-of-way.[8]

[2] APPENDIX 3. ELECTRIC AND MAGNETIC FIELDS AND OTHER FIELD-RELATED CONCERNS https://ia.cpuc.ca.gov/Environment/info/aspen/viejosystem/final_apps/App%203-EMF%20Health%20Effects.pdf

[3] Connecticut Public Act 04-246 (codified under Connecticut General Statutes § 16-50p); Comments of Richard Blumenthal, Attorney General for the State of Conn., Concerning P.A. 04-146, Conn. Siting Council Docket No. 272 (July 19, 2004)

[4] Hawaii DOH POLICY RELATING TO ELECTRIC AND MAGNETIC FIELDS FROM POWER-FREQUENCY SOURCES,(1994) https://www.hawaiianelectric.com/documents/about_us/environment/EMF_DOH_PUC_combined.pdf

[5] Section 403.061(30), Florida Statutes and the rule is 62-814, Florida Administrative Code. Compliance with the EMF standards is demonstrated through monitoring and reporting by the utilities. Section 62-814.450 - Electric and Magnetic Field Standards

[6] Can be waived by landowner

[7] Florida Building Code §468.2.4 (2023 ed.) / §453.10.9 Transmission Line Right-of-Way | UpCodes

[8] Iowa 2025 Iowa Code. Title XI - NATURAL RESOURCES. Chapter 478 - ELECTRIC TRANSMISSION LINES Section 478.20 - Distance from buildings.

Minnesota[9]	Within right-of-way	8	NA
No high voltage transmission line may be routed through state or national parks, historic, scientific and natural areas unless the transmission line would not materially damage or impair the purpose for which the area was designated and no feasible and prudent alternative exists. Economic considerations alone do not justify use of these areas. **Prime farmland exclusion.** No large electric power generating plant site may be permitted where the developed portion of the plant site, excluding water storage reservoirs and cooling ponds, includes more than 0.5 acres of prime farmland per megawatt of net generating capacity,			
Montana[10]	Within right-of-way: road crossing	7	NA
	Edge of right-of-way	1[2]	NA
New Jersey[11]	Within right-of-way	NA	NA
	Edge of right-of-way	3	NA
New York[12]	Within right-of-way: open	11.8	NA
	Within right of way: public road	7	NA
	Within right of way: private road	11	NA
	Edge of right of way	1.6	200
	Applicants for major transmission projects are required to prepare EMF studies that model EMF (baseline and proposed with multiple loading conditions, out 500 feet beyond right of way on both sides.[13]		
North Dakota[14]	Within right of way	9	NA
	Edge of right of way	NA	NA

[9] The Minnesota 8 kV 1m maximum field limit is applied on a case-by-case basis by the Minnesota Environmental Quality Board (MEQB), which has jurisdiction over lines of nominal voltage 200kV and higher. The limit is included in construction permits granted by the MEQB rather than in a formal rule [e.g., Minnesota Environmental Quality Board (MEQB), 1977]. Minnesota does not have an edge-of-right-of-way field limit. 12 kV 1m limit on the HVDC nominal electric field. MPUC Large Energy Infrastructure Guidance.

[10] Minnesota Administrative Rules CHAPTER 7850, SITE OR ROUTE PERMIT; POWER PLANT OR LINE https://www.revisor.mn.gov/rules/7850/full

[11] Guideline established in 1981 by the New Jersey Department of Environmental Protection (NJDEP).

[12] Article VII, "Siting of Major Utility Transmission Facilities," is the section of the New York State Public Service Law that requires EMF studies and disclosure for major transmission projects https://dps.ny.gov/article-vii-major-electric-and-gas-transmission-facilities New York PSC policy directs utilities to design transmission lines so magnetic fields at the edge of the right-of-way generally do not exceed 200 milligauss under normal operating conditions. See also https://dps.ny.gov/article-vii-major-electric-and-gas-transmission-facilities, The New York State Certification Review Process For Major Electric and Fuel Gas Transmission Facilities and Siting New Energy Infrastructure Issue Brief New York State Energy Plan 2009

[13] As examples, the NY National Grid Lockport-Mortimer Line 111 Rebuild Project i 56-mile, 115 kV single-circuit transmission line. Appendix D: EMF Study link; FLAT CREEK SOLAR Permit Application No. 23-00054;

[14] An informal requirement of the North Dakota Public Service Commission (NDPSC).

Five hundred foot [152.4 meter] avoidance area criteria for an inhabited rural residence may be waived by the owner of the inhabited rural residence in writing.[15]			
Ohio[16] If the centerline of a proposed transmission facility or the boundary of a substation footprint is within 100 feet of an occupied residence or institution, the utility must provide electric and magnetic field strength levels, references on the current state of knowledge and the company policy on EMF.			
Oregon[17]	Areas accessible to the public, 1 meter above ground	9	NA
	Within right of way	9	NA
	Edge of right-of-way	NA	NA
The Bonneville Power Administration maintains a prohibition on playground equipment and similar recreational structures directly beneath or near its power lines.[18]			
Virginia The Virginia State Corporation Commission (SCC) is legally mandated to evaluate the environmental impacts of any proposed high-voltage transmission line project (typically 138 kV or larger). The SCC's official Guidelines for Transmission Line Applications explicitly require utilities to submit detailed electric and magnetic field (EMF) calculations. However, they are not required to provide that information in the early stages during the preliminary route-refinement and community outreach phase.			

Utility	
San Diego Gas & Electric (SDG&E)	Encroachment guide for its transmission ROW: developers must comply with all applicable state/county/local rules, and are pointed specifically to CA Dept. of Education's school-siting distance guide[19]

[15] North Dakota Century Code § 49-22-05.1(3) s "Except for electric transmission lines in existence before July 1, 1983, areas within five hundred feet [152.4 meters] of an inhabited rural residence must be designated avoidance areas. This criterion does not apply to a water pipeline. The five hundred foot [152.4 meter] avoidance area criteria for an inhabited rural residence may be waived by the owner of the inhabited rural residence in writing." Rule governing the 500-foot state setback standard is legally codified under North Dakota state statute, and the specific mechanism granting the state authority over local zoning was passed via House Bill 1258.The bill amended North Dakota Century Code § 49-22-16(2), clarifying that route permits approved by the Public Service Commission (PSC) for electric transmission facilities supersede local zoning ordinances if an applicant demonstrates that local requirements are unreasonably restrictive.

[16] Ohio Administrative Code Rule 4906-4-08(A)(14)

[17] OAR 345-024-0090 Siting Standards for Transmission Lines

[18] https://www.bpa.gov/environmental-initiatives/land-and-right-of-ways/land-and-rights-of-way-resource-library

[19] GUIDE FOR ENCROACHMENT SDG&E ELECTRIC TRANSMISSION RIGHTS OF WAY

Comparison of Health-Based Magnetic Field Levels and Regulatory Limits

When evaluating the potential health risks of magnetic fields from proposed high-voltage transmission lines, it is important to compare the industry presented limits with the magnetic field EMF levels at which scientific studies have reported health effects.

However, U.S. IEEE and international ICNIRP exposure limits (9,100 mG and 2,000 mG, respectively) are based only on preventing short-term acute effects such as nerve stimulation and explicitly do not address cancer or other potential long-term health effects. International scientific organizations acknowledge that epidemiological studies have consistently linked long-term magnetic field exposure above approximately 3–4 mG (0.3–0.4 μT) with an increased risk of childhood leukemia. In response, several countries recommend limiting long-term exposure, particularly for children. Since the WHO IARC classified extremely low-frequency magnetic fields as a Group 2B Possible Human Carcinogen in 2001, additional peer-reviewed studies have continued to report associations with childhood leukemia as well as other health issues such as Alzheimer's disease, with some studies reporting elevated risks at magnetic field levels as low as 1–3 mG.

Table 4 compares the magnetic field levels at which scientific studies have reported health effects with the much higher exposure limits established by regulatory organizations.

Entity	Policy or Recommendation to Limit Public Exposure	Magnetic Field (mG)
IEEE, 2019[20]	IEEE limits are only designed to protect against the "established" acute (short term exposure) effects of pain and involuntary muscle contractions related to electrostimulation of nerves and muscles. They are not designed to address cancer or effects of long term exposure. IEEE states the limits "do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks" and are "not intended to apply to the exposure of patients by or under the direction of physicians and medical professionals… and might not be protective with respect to the use of medical devices or implants."	9,100
ICNIRP, 2010[21][22]	ICNIRP states that its limits are based on "established" acute (short-term exposure) effects of primarily nerve stimulation, shock and burn. ICNIRP limits are not based on cancer risk. ICNIRP states: "epidemiological studies have consistently found that everyday chronic low-intensity (above 0.3– 0.4 T) [3-4 mG] power frequency magnetic field exposure is associated with an increased risk of childhood leukemia. IARC	2,000

[20] International Committee for Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz. IEEE Std C95.1-2019 New York, NY: IEEE, 2019 PDF

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[22] International Commission on Non-Ionizing Radiation Protection (ICNIRP). ICNIRP Statement - Guidelines for Limiting Exposure to Electromagnetic Fields (1 Hz to 100 kHz). Health Phys 99:818-836, 2010); This was based on revised estimates of the threshold for acute nerve stimulation allowing a doubling of the level. The 1998 ICNIRP guidelines had set the public reference level for 50 Hz magnetic fields at 1000 mG and for 60 Hz at 830 mG.

	has classified such fields as possibly carcinogenic. However, a causal relationship between magnetic fields and childhood leukemia has not been established nor have any other long-term effects been established. The absence of established causality means that this effect cannot be addressed in the basic restrictions." ICNIRP changed its Guidelines in 2010, as it was previously 1000 mG.	
European Union 1999/519/EC	Many European countries such as Estonia, Greece, Austria, Portugal, Hungary and Cyprus have adopted policies with the 1999 limit recommended by the EU- Magnetic field of 100 µT or 1,000 mG, half of ICNIRP limits and about one-ninth (11%) of the IEEE limit.	1,000
Countries include; Netherlands, Finland, Denmark, Belgium, Israel	Avoiding situations in which children are exposed for long periods at home and/or school due to scientific research linking exposure to childhood leukemia.	4
European Commission Scientific Committee (SCENIHR), 2015[23]	While they conclude no causal relationship is "proven" they state "The new epidemiological studies are consistent with earlier findings of an increased risk of childhood leukaemia with estimated daily average exposures above 0.3 to 0.4 µT. [3-4 mG]"	3-4
WHO International Agency for Research on Cancer, 2001[24]	Classified extremely low-frequency magnetic fields as a Group 2B Possible Human Carcinogen in 2001 based primarily on studies linking long-term childhood EMF exposure above approximately 0.3–0.4 µT (3–4 mG) with increased leukemia risk.	3-4
National Institute of Environmental Health Sciences, 1998[25]	"A majority of the Working Group concluded that classification of ELF EMF as possibly carcinogenic (Group 2B) is a conservative, public-health decision based on limited evidence of an increased risk for childhood leukemias with residential exposure and an increased occurrence of CLL associated with occupational exposure."	3-4
Bio-Initiative Report recommendation 2007[26]	"It is also recommended for that a 1 mG limit be established for existing habitable space for children and/or women who are pregnant (because of the possible link between childhood leukemia and in utero exposure to ELF)."	1
Building Biology Guidelines	"The Building Biology Evaluation Guidelines are based on the precautionary principle. They are specifically designed for sleeping	.2

[23] https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf

[24] Non-ionizing Radiation, Part 1: Static and Extremely Low-frequency (ELF) Electric and Magnetic Fields. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 80;

[25] NIEHS 1998. Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. Working Group Report (Portier C, Wolfe M, eds). NIH publication no. 98-3981. Research Triangle Park, NC:National Institute of Environmental Health Sciences

[26] "ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor. It is no longer acceptable to build new power lines and electrical facilities that place people in ELF environments that have been determined to be risky…It is also recommended for that a 1 mG limit be established for existing habitable space for children and/or women who are pregnant (because of the possible link between childhood leukemia and in utero exposure to ELF). " https://bioinitiative.org/wp-content/uploads/pdfs/sec01_2007_summary_for_public.pdf

Germany (SleepingAreas)[27]	areas associated with long-term risks and a most sensitive window of opportunity for regeneration."	
Examples of Peer Reviewed Scientific Research		
Cancer	In the decades since the IARC 2001 classification, several new studies[28] and reviews of the research have continued to associate long term exposure to childhood leukemia[29] as well as poorer survival.[30] Peer reviewed scientific studies have also reported increased risk for brain[31] and central nervous system[32] tumors, breast cancer[33] and melanoma[34]. Case-control studies[35] on children with Downs syndrome (who have a 20-fold increased risk of developing leukemia) suggest magnetic fields may act as a promoter or causal factor in this genetically susceptible subgroup of children. Another study of childhood leukemia cases near elevated powerline EMF levels found evidence that certain genetic	3-4

[27] https://www.baubiologie.de/downloads/english/richtwerte_2008_englisch.pdf

[28] Lowenthal RM, Tuck DM, Bray IC. Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study. Intern Med J. 2007 Sep;37(9):614-9. doi: 10.1111/j.1445-5994.2007.01389.;Draper G, Vincent T, Kroll M E, Swanson J. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study BMJ 2005; 330 :1290 doi:10.1136/bmj.330.7503.1290; Kabuto, M., Nitta, H., Yamamoto, S., Yamaguchi, N., Akiba, S., et al., 2006. Childhood leukemia and magnetic fields in Japan: a case-control study of childhood leukemia and residential power=-frequency magnetic fields in Japan. Int. J. Cancer 119, 643–650; Schuz, J., Svendsen, A.L., Linet, M.S., McBride, M.L., Roman, E., Feychting, M., et al., 2007. Nightime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis. Am. J. Epidemi 9l 166, 263–269.; Feizi AA, Arabi MA. Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines - a risk factor in Iran. Asian Pac J Cancer Prev. 2007 Jan-Mar;8(1):69-72. PMID: 17477775.; Abdul Rahman HI, Shah SA, Alias H, Ibrahim HM. A case-control study on the association between environmental factors and the occurrence of acute leukemia among children in Klang Valley, Malaysia. Asian Pac J Cancer Prev. 2008 Oct-Dec;9(4):649-52. PMID: 19256754; Sohrabi MR, Tarjoman T, Abadi A, Yavari P. Living near overhead high voltage transmission power lines as a risk factor for childhood acute lymphoblastic leukemia: a case-control study. Asian Pac J Cancer Prev. 2010;11(2):423-7. PMID: 20843128.; Tabrizi MM, Bidgoli SA. Increased risk of childhood acute lymphoblastic leukemia (ALL) by prenatal and postnatal exposure to high voltage power lines: a case control study in Isfahan, Iran. Asian Pac J Cancer Prev. 2015;16(6):2347-50. doi: 10.7314/apjcp.2015.16.6.2347. PMID: 25824762.

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	variants related to DNA repair may make some children more susceptible to the effects.[36]	
Dementia and Alzheimer's	Studies have reported higher rates of dementia and Alzheimer's disease close to high voltage powerlines.[37]	Starting at .5 mG with the stronger associations at 1–3 mG.

Local U.S. Government Policies That Are More Protective Than State Requirements

Communities are increasingly adopting local setback requirements to create greater separation between high-voltage transmission lines and homes.

There is a range of setbacks. For example:

- Deuel County, South Dakota, adopted one of the strongest local transmission line setback ordinances in the United States, requiring new 345 kV and higher transmission lines to be located at least 2,000 feet from homes, although the ordinance was later amended so that landowners can consent to reduced setbacks.
- Brookings County, South Dakota has a 1,000 foot setback.
- The Stutsman County Commission in Jamestown, North Dakota, officially approved a revised zoning ordinance requiring a 1,000-foot setback distance between high-voltage electrical transmission lines and occupied dwellings in 2025.
- Homer Township and Corwin Township, which control their own zoning independently of the county) had each passed their own half-mile (2,640 ft) setback specifically to block the JETx transmission project. However, under North Dakota state law (HB 1258), local zoning ordinances can be superseded by the Public Service Commission if local requirements are deemed unreasonably restrictive.

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- Power County, Idaho has a 1,500-foot setback from residences, schools, hospitals, colleges, and daycare centers as well as wetlands, floodplains, historic sites and critical-species habitat.
- Lambertville, New Jersey: 100 ft: New residential buildings may not be located within 100 feet of the vertical plane of the nearest high-voltage transmission conductor.
- West Hempfield Township, Pennsylvania: 75 ft: Dwellings must be set back at least 75 feet from a high-voltage transmission-line right-of-way.
- Sacramento County, California: For residential areas, Sacramento County has a different policy: it says every reasonable effort should be made to avoid established residential areas, and if a 100 kV+ line must be routed through one, it should be underground unless undergrounding is shown to be infeasible.

Notable Positions

Loudoun County, Virginia Board of Supervisors: In January 2025, Board also called for the burial of any transmission lines planned to pass closer than 500 feet from any residence or public school; however, Loudoun County does not have any authority to require underground transmission lines.

Fluvanna County, Virginia: The Planning Commission advanced draft transmission-line siting rules (July 2026) that would require 200 feet from occupied homes and community buildings, 100 ft from roads/wetlands/streams, and 75 ft from nonparticipating property lines, plus mandatory alternative-site analysis and visual/sound studies.

The Village of Ardentown, Delaware, originally passed Ordinance #2025-02 to prohibit the construction of any new transmission lines or towers at or above 60 kilovolts within a 100-foot radius of residential housing units, but the law was quickly rescinded following a lawsuit by Delmarva Power in Delaware's Court of Chancery. Facing escalating legal fees and severe financial penalties, the Ardentown trustees officially vacated the restriction, mirroring a move by the neighboring village of Ardencroft, which rescinded its own similar ordinance and fee structure on October 13, 2025, due to the same utility litigation.

- 'Tree huggers' of Arden battle to cut down Delmarva Power's plan to replace electric towers in their village

Policy Recommendations

The United States lacks a comprehensive public health regulatory framework governing electromagnetic field (EMF) exposure from electrical infrastructure. Unlike air pollution, drinking water, or hazardous chemicals, there are no federal health-based exposure standards, no nationwide EMF measuring or monitoring program, no setback requirements for schools or hospitals, no post-construction compliance program, and no requirement that utilities publicly disclose EMF levels before or after projects are built.

The appropriate framework for regulating EMF exposure is a public health risk mitigation approach. History has repeatedly shown that by the time causation is considered fully "established," countless people have already been harmed. Rather than waiting decades for absolute scientific certainty, policymakers should reduce unnecessary exposure where credible evidence of risk exists, particularly for children.

As new high voltage transmission lines and substations are rapidly expanding to serve AI data centers, policymakers should adopt a comprehensive public health risk mitigation framework that emphasizes transparency, exposure reduction, and protection of vulnerable populations such as children and pregnant women.

Federal Regulatory Reform Recommendations

- **Science Based Safety Standards:** Congress should restore a federal EMF public health program within health and environmental agencies to independently review the scientific evidence and develop public health-based limits and recommendations for long-term EMF exposure. The United States should no longer rely solely on IEEE and ICNIRP engineering guidelines, which were developed only to prevent short-term nerve stimulation and do not address long-term outcomes such as cancer, neurodegenerative disease, reproductive effects, or childhood health.
- **Nationwide Monitoring Program:** Federal agencies should establish a nationwide EMF monitoring and reporting program similar to existing air and water quality monitoring systems.
- **Transparency:** Utilities should be required to model, measure, and publicly disclose electric and magnetic field levels before construction, after projects become operational, and periodically throughout the life of the facility. This should include levels not only at the edge of the ROW, but also at least 100-500 feet out so that the public is informed of the exposures in their homes, workplaces, recreation areas and schools.
- **Compliance and Oversight:** Federal regulations should also require post-construction compliance monitoring, independent verification of EMF modeling, and corrective action if actual field levels exceed projected levels or if future system upgrades substantially increase exposures.
- **Health and Environmental Review:** Federal permitting for new high-voltage transmission lines, substations, and major electrical infrastructure should require Health Impact Assessments evaluating potential impacts on human health, children, agriculture and wildlife.
- **Burden of Demonstrating Exposure Reduction:** Applicants for new transmission lines and substations should be required to demonstrate that the proposed project has been designed and routed to minimize public EMF exposure to the greatest extent reasonably achievable, and that reasonable alternatives with lower public exposure have been evaluated before approval.

Policy Recommendations: Protecting Wildlife and Ecosystems

Current U.S. permitting for high-voltage transmission lines largely evaluates wildlife impacts through habitat loss, vegetation clearing, and bird collisions. However, environmental reviews generally do not assess the biological effects of EMF on wildlife, despite a growing body of scientific literature documenting effects on pollinators, birds, fish, mammals, and other species. Credible evidence of ecological harm has been identified, particularly for threatened, endangered, or declining species. Thus, exposures should be reduced and EMF should be evaluated as an environmental stressor alongside other project impacts.

A comprehensive set of recommendations are detailed in the policy review paper by Levitt et al. (2025) published in Frontiers in Public Health entitled, "Flora and fauna: how nonhuman species interact with natural and man-made EMF at ecosystem levels and public policy recommendations."Federal and state agencies should:

- Require environmental impact assessments for new transmission lines and substations to evaluate EMF effects on wildlife, including pollinators, birds, mammals, amphibians, and aquatic species.
- Develop science-based EMF exposure guidelines that protect wildlife, recognizing that current engineering standards were developed only to prevent acute effects in humans and do not evaluate ecological impacts.
- Avoid locating new transmission corridors, substations, and associated infrastructure adjacent to wildlife refuges, conservation lands, critical habitat, wetlands, fish spawning areas, migratory corridors, and other ecologically sensitive areas whenever feasible.
- Require utilities to evaluate cumulative environmental impacts, including interactions between EMF exposure and other stressors such as pesticides, habitat fragmentation, climate change, and pollution.
- Expand federal research programs to investigate long-term ecological impacts of EMFs from electrical infrastructure.
- Establish long-term ecological monitoring programs before and after construction to evaluate wildlife populations, pollinator abundance, reproductive success, biodiversity, and habitat quality near transmission corridors and substations.
- Incorporate wildlife experts, ecologists, and environmental health scientists into transmission planning and permitting decisions to ensure biological impacts receive the same consideration as engineering and economic factors.

State and Local Public Health and Siting Policy Recommendations

While comprehensive federal oversight is needed, states and local governments are not powerless. Through land-use planning, utility regulation, public disclosure requirements, and siting policies, they can reduce unnecessary EMF exposure, improve transparency, and better protect homes, schools, farms.

- **Risk Mitigation:** States and municipalities should adopt EMF policies that prioritize exposure reduction where people live, work, learn, and receive medical care. The approach should be one of risk management.
- **EMF Limits:** States can set stringent limits for electric and magnetic exposure.

- **Setbacks:** Establish minimum setback distances for new transmission lines and substations and avoid routing near to:
    - Homes
    - Schools
    - Daycare centers
    - Playgrounds
    - Parks
    - Hospitals
    - Nursing homes
- **Protect Children and Vulnerable Populations:** prohibit new schools, childcare facilities, playgrounds, and athletic fields from being located adjacent to high-voltage transmission corridors.
- **Documentation:** Require utilities to document and use engineering approaches that minimize EMF exposure including optimum phasing, conductor configuration, line design, and other low-cost mitigation measures.
- **Transparency and Public Right-to-Know:** Utilities should be required to publicly disclose:
    - Existing baseline EMF measurements before construction.
    - Projected magnetic and electric field levels after construction.
    - Utilities should disclose future loading assumptions so communities understand how EMF levels may change as electrical demand grows.
    - EMF contour maps showing exposures at homes, schools, parks, hospitals, and property lines.
    - Expected future EMF levels under increased electrical demand.
    - Harmonic distortion analyses.
    - Corona discharge assessments.
    - Audible noise studies.
    - Post-construction monitoring reports.
    - How stray voltage resorts will be addressed.

  Projected EMF levels should be shared in the very early stages, during public outreach, not just in permit applications. This information should be maintained in publicly accessible online databases.

Key Elements of Project Review

- Local governments should include EMF data as part of project review for transmission lines, substations, and electrical infrastructure serving large data centers. Counties and municipalities should require applicants to provide independent EMF modeling, baseline measurements, projected EMF levels after construction under typical, peak, and future loading conditions, post-construction monitoring, and annual public reporting. This should include EMF levels not only at the edge of the ROW, but also at least 100-1000 feet out so that the public is informed of the exposures in their homes, workplaces, recreation areas and schools.
- Undergrounding should be required unless the applicant can demonstrate why not.

- An explanation of the engineering methods used to minimize EMF, including conductor configuration, phasing, routing alternatives, structure height, and other mitigation measures.
- Fire hazards should be evaluated as a core component of every project. Local governments should require independent wildfire risk assessments, consider cumulative fire risks, and ensure that emergency response capabilities and evacuation planning are incorporated into project approval decisions.
- Project applicants should evaluate potential impacts on livestock health, dairy operations, pollinators, birds, wildlife habitat, fish and aquatic ecosystems.
- Environmental review should also evaluate induced voltage, stray voltage, harmonic distortion, herbicide use within rights-of-way, habitat fragmentation, and cumulative impacts associated with transmission infrastructure.

Examples of State Laws

1. EMF Transparency and Disclosure Act

Require utilities to publicly disclose existing and projected electric and magnetic field (EMF) levels before construction of new transmission lines, substations, and major electrical infrastructure. Applicants should provide baseline measurements, EMF modeling under normal, peak, and future loading conditions, contour maps extending beyond the right-of-way, and post-construction monitoring results. All studies, modeling reports, and monitoring data should be maintained in a publicly accessible online database.

2. EMF Health Protection and Risk Mitigation Act

Require utilities to minimize public EMF exposure through feasible engineering, siting, and design measures. Project applicants should demonstrate that alternative routes, undergrounding where appropriate, conductor configuration, phase optimization, and other exposure-reduction techniques have been evaluated before approval. States should adopt a public health risk mitigation framework that seeks to reduce unnecessary long-term EMF exposure, particularly where children and other vulnerable populations may be affected.

3. Sensitive Land Use Protection Act

Establish minimum setback requirements or avoidance policies for new high-voltage transmission lines and substations near schools, childcare centers, hospitals, nursing homes, playgrounds, parks, and residential neighborhoods. Where setbacks cannot be achieved, applicants should be required to demonstrate that no feasible alternative exists and that all reasonable measures have been taken to minimize EMF exposure.

4. Comprehensive Health and Environmental Review Act

Require all major transmission line and substation projects to undergo a comprehensive Health and Environmental Impact Assessment before permitting. In addition to EMFs, the review should evaluate induced voltages, harmonic distortion, corona discharge, audible noise, impacts on individuals with implanted medical devices, livestock, agriculture, pollinators, wildlife, and cumulative environmental impacts. Applicants should also identify the scientific evidence relied upon to support any conclusion that projected EMF levels are protective of public health.

Recommended Questions Policymakers and the Public Can Ask When a Power Line or Substation Is Proposed Near Your Home or Community

Here are questions community members and local officials can ask.

What are the maximum electric and magnetic fields that any home, school, business, or property line near the power line or substation could experience during peak electrical loading over the lifetime of the project.

Baseline EMF Measurements

- What are the current EMF levels in milligauss at nearby homes, schools, parks, and property lines before construction begins?
- Send the baseline measurements, with details on the date and load details when EMF measurements were taken.

Projected EMF Increases

- What EMF levels are expected after the project is operating? Will there be increases, and if so, by how much? Provide EMF modeling showing field levels at different distances from the project beyond the ROW. Clarify the increase over baseline.
- What are the highest EMF levels expected during peak electrical demand?
- How far from the transmission line, substation, or data center do elevated EMF levels extend? Send numerical calculations.
- What design measures are being used to mitigate EMF exposure for nearby residents, schools, and businesses?
- If future equipment is added or electrical demand increases, how will EMF levels change? Has this been evaluated?
- What setback distance or EMF limit was used to determine that the project is safe for nearby residents?

Post-Construction Monitoring

- Will post-construction EMF measurements be performed, and will the results be publicly available?
- Will there be ongoing EMF monitoring (yearly, monthly, continuous) after the facility is operational, and who will be responsible for that monitoring?

Transparency

- Where can residents access the EMF studies, modeling reports, and measurement data related to the project?
- Will all future EMF measurement reports and monitoring results be made publicly available? If so, where?
- If measured EMF levels exceed projections, what corrective actions will be taken and how will the public be notified?
- If the company concludes that the projected EMF levels present no health risk to humans, livestock, wildlife, including pollinators, what specific scientific evidence and studies support that conclusion?

Safety

- What scientific studies are being relied upon to support claims that the projected EMF levels are safe for nearby residents? List full scientific studies with links.
- Have the projected EMF levels been compared to the 4 mG magnetic field level that has been associated with increased childhood leukemia risk in multiple epidemiological studies?

Agriculture, and Wildlife

- What scientific studies are being relied upon to support claims that the projected EMF levels are safe for livestock and wildlife? List all scientific studies with links.
- Have any studies been conducted evaluating potential impacts on livestock, horses, dairy operations, or agricultural productivity in the vicinity of the project?
- Have any studies been conducted evaluating impacts on pollinators, including honey bees and native bee populations?
- Have any studies been conducted evaluating impacts on birds and avian mortality?
- Are there any studies, reports, or analyses that have found associations between high-voltage transmission line exposure and adverse effects on human health, livestock health, or agricultural productivity? If so, can they be provided to the public?

Sensitive Populations

- Has the project evaluated potential impacts on individuals with pacemakers, implantable cardioverter defibrillators (ICDs), insulin pumps, cochlear implants, or other implanted medical devices?
- Are any setback distances or special precautions recommended for residents with implanted medical devices?

Stray Voltage and Electrical Safety

- At what distances from the proposed transmission line have induced voltages on fences, irrigation systems, buildings, and farm equipment been modeled, and what mitigation measures will be provided?
- If stray voltage is detected after the line is energized, who will be responsible for mitigation and associated costs?
- Will the utility conduct post-construction stray voltage testing on nearby properties, particularly farms and agricultural operations?
- How frequently will the utility monitor for stray voltage after the project becomes operational?
- Will the utility provide the complete results of all stray voltage testing to affected property owners?

Corona discharge: Communities should not only ask how strong these emissions will be, but also how far they will extend from the line. Developers should be required to disclose the expected distance over which corona-related radio interference, audible noise, and other effects may be detectable under both normal and adverse weather conditions.
Induced voltage:

- What are the predicted noise levels (dBA) at the edge of the right-of-way, nearby homes, schools, farms, and parks?
- How far beyond the transmission line are corona-related effects including audible noise, radio interference, ozone generation, and other emissions expected to extend under both normal and adverse weather conditions?
- At what distances from the proposed transmission line have induced voltages on fences, irrigation systems, buildings, pipelines, and farm equipment been modeled, and what mitigation measures will be provided?
- Will post-construction measurements of corona-related emissions, audible noise, radio interference, and induced voltages be conducted to verify the modeling, and will those results be made publicly available?
- If measured levels exceed the projected values or create impacts for nearby residents or agricultural operations, what corrective actions will the utility be required to take?

A list of testimonies by scientific experts documenting the published research on EMF and health filed in previous legal cases on power lines and substations?

Dr. Martin Blank, Columbia University

- **Prepared Testimony of Professor Martin Blank in the Virginia (SCC PATH 765kV Case PUE 2009-00043)**

> "There can be no doubt that the proposed addition of the 765kV line to the existing 500kV line 138 kV lines would add to the level of EMF and thereby create additional potential risk. This would be contrary to the recommendations of the May 1999 NIEHS Report to Congress."

Dr. David Carpenter

East Kentucky Power Cooperative, 345/138-kV transmission line
April 25, 2014 filing titled "Harold Barker, Ann Barker, and Brooks Barker Direct Testimony of Witnesses." Dr. Carpenter Affidavit starts at page 21

Robert O. Becker, M.D.

1987 Congressional Hearings on the Health Effects of Powerlines, October 6, 1987

- Transcript of 1987 Congressional Hearing
- Dr. Becker Statement before the House Subcommittee on Water and Power Resources: Congressional Hearings on the Health Effects of Powerlines, October 6, 1987.[PDF]
- News: Power lines pose possible cancer risk: 1987 Congressional Hearing

From Robertobecker.net
"In 1972 he delivered a paper at an annual convention of the IEEE in which, based on considerations regarding the body's cybernetic control system, he warned against "the continuous exposure of the entire North American population to an electromagnetic environment in which is present the possibility of inducing currents or voltages comparable with those now known to exist in biological control systems." Subsequently he reported experimental studies in which animals were exposed for relatively long times to artificial electromagnetic energy. Employing energy levels comparable to those in the general environment, he found that continuous exposure to the energy for periods of weeks or months caused altered growth rates in mice, deficient bone healing in rats, stress-related changes in the neuroendocrine system in rats, and chromosome changes in tumor cells. He published explanations of his work and that of others who found similar results, and in several publications discussed the implications of the animal studies with regard to human health risks. In a New York hearing on the safety of high-voltage powerlines, he testified in favor of independent research regarding the health risks of artificial environmental electromagnetic energy, and was cross-examined for four days. He gave similar testimony before a congressional committee. Becker was the first to use the term "electromagnetic pollution."

- Prepared statement for the Committee on Interior and Insular Affairs of the House of Representatives concerning health and public policy implications of electric powerlines. March 8, 1990. [PDF]

- Prepared testimony before the State of New York, Public Service Commission in connection with Cases 26529 and 26559—Common Record Hearings on Health and Safety of 765 kV Transmission Lines. November, 1975. [PDF]

More at https://robertobecker.net

Testimony of Andrew A. Marino, Ph.D., J.D.

"POINT 1: The overwhelming weight of the credible scientific evidence shows that the electric field and the magnetic field of the proposed transmission lines will each cause biological effects in the human beings exposed to them."- CASE 26529/26559—Common Record Hearings on the Health and Safety of 765 kV Transmission Lines July, 1977 Amicus Curiae Brief Submitted By ANDREW MARINO

- In the Matter of: The Application for Certification of Pacific Gas and Electric Company Re: Geysers Unit 16.Docket No. 79-AFC-5. California, August 4, 1980. [PDF]
- A.A. MARINO & R.O. Becker. Med. Res. Eng. 12: 6–9, 1978. [PDF]
- Amicus Curiae Brief on Exceptions, submitted by Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York.
- State of New York, Public Service Commission, Cases 26529 AND 26559—Common Record Hearings on Health and Safety of 765 kV Transmission Lines, February 1978. [PDF]
- Electromagnetic pollution.R.O. Becker & A.A. MARINO. The Sciences, January, 1978, pp. 14, 15, 23. [PDF]
- Amicus Curiae Reply Brief submitted by Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York. State of New York, Public Service Commission, Cases 26529 AND 26559— Common Record Hearings on Health and Safety of 765 kV Transmission Lines, September 1977. [PDF]
- Amicus Curiae Brief submitted by Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York. State of New York, Public Service Commission, Cases 26529 AND 26559— Common Record Hearings on Health and Safety of 765 kV Transmission Lines, July 1977. [PDF]
- Prepared Testimony of Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York. In the Matter of: The Application for Certification of Pacific Gas and Electric Company Re: Geysers Unit 16. Docket No. 79-AFC-5. California, June 17, 1977. [PDF]
- Rebuttal Testimony of Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York. State of New York, Public Service Commission, Cases 26529 AND 26559—Common Record Hearings on Health and Safety of 765 kV Transmission Lines, November 1976. [PDF]
- Prepared Testimony of Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York. State of New York, Public Service Commission, Cases 26529 AND

26559—Common Record Hearings on Health and Safety of 765 kV Transmission Lines, November1975. [PDF]

- Prepared Testimony of Andrew A. Marino, Ph.D., J.D., Veterans Administration Hospital Syracuse, New York. State of New York, Public Service Commission, Case 26559 – Rochester Gas and Electric Corporation and Niagara Mohawk Power Corporation: Pannell Road to Volney and Oswego to Sterling Transmission Facilities, October 1974. [PDF]

A list of key peer reviewed research reviews and studies

Key Published Scientific Reviews

Brabant C, Honvo G, Demonceau C, Tirelli E, Léonard F, Bruyère O. Effects of extremely low frequency magnetic fields on animal cancer and DNA damage: a systematic review and meta-analysis. Prog Biophys Mol Biol. 2024 Dec 31:S0079-6107(24)00116-0. doi: 10.1016/j.pbiomolbio.2024.12.005.

Sun, J. W., Li, X. R., Gao, H. Y., Yin, J. Y., Qin, Q., Nie, S. F., & Wei, S. (2013). Electromagnetic field exposure and male breast cancer risk: a meta-analysis of 18 studies. Asian Pacific journal of cancer prevention : APJCP, 14(1), 523–528.

Seomun, G., Lee, J., & Park, J. (2021). Exposure to extremely low-frequency magnetic fields and childhood cancer: A systematic review and meta-analysis. PLOS ONE, 16(5), e0251628.

Brabant, C., Geerinck, A., Beaudart, C., Tirelli, E., Geuzaine, C., & Bruyère, O. (2022). Exposure to magnetic fields and childhood leukemia: A systematic review and meta-analysis of case-control and cohort studies. Reviews on Environmental Health.

Carles, C., Esquirol, Y., Turuban, M., Piel, C., Migault, L., Pouchieu, C., Bouvier, G., Fabbro-Peray, P., Lebailly, P., & Baldi, I. (2020). Residential proximity to power lines and risk of brain tumor in the general population. Environmental Research, 185, 109473.

Carpenter, D. O. (2013). Human disease resulting from exposure to electromagnetic fields. Reviews on Environmental Health, 28(4), 159–172.

Carpenter, D. O. (2019). Extremely low frequency electromagnetic fields and cancer: How source of funding affects results. Environmental Research, 178, 108688.

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Is there evidence that high-voltage power lines reduce property values and negatively affect the financial well-being of surrounding communities?

A study published in the Journal of Real Estate Research conducted out of the College of Charleston in Charleston, South Carolina determined that properties adjacent to high voltage power lines experienced discounts of 44.9% of their value and properties that were up 1,000 feet away had a pricing discount of 17.9%.
The study was featured in "The Electrifying Factor Affecting Your Property's Value," The Wall Street Journal (Aug. 15, 2018)

A study in the UK found high-voltage overhead transmission lines (HVOTLs) reduce residential property values by 6-17%, averaging 11.5% within 100 meters and proximity can decrease property value by up to 20.7% compared to those 250 meters away. Note: This study was from 2005 and there are no 765 kV power lines in the UK. The highest alternating current (AC) transmission voltage used on the National Grid is 400 kV.

A Report An Economic Assessment of the 765-kV Strategic Transmission Expansion Plan by Brent Bennett, Ph.D. argues that Texas policymakers should pause implementation of ERCOT's 765-kV Strategic Transmission Expansion Plan (STEP) and consider alternatives to minimize the cost and impact because the plan "would impose nearly $100 billion in lifetime costs on Texas ratepayers and result in irreversible property losses for thousands of landowners across the state."

This report is a living document and is updated regularly. Please get the updated report at this link. Contact us with questions and clarifications.