UNDERSTANDING ELECTRIC AND MAGNETIC FIELDS

In Association with HVDC Transmission Lines

CLEAN LINE
ENERGY PARTNERS

THIS BROCHURE IS INTENDED TO EDUCATE AND PROMOTE A FACT BASED UNDERSTANDING OF HVDC TRANSMISSION AND ASSOCIATED ELECTRIC AND MAGNETIC FIELDS.

HVDC TRANSMISSION LINES

Historically, the transfer of electricity between regions of the country has been over high-voltage alternating current (AC) transmission lines, which means that both the voltage and the current on these lines move in a wave-like pattern along the lines and continually change direction. In North America, this change in direction occurs 60 times per second (defined as 60 Hertz [Hz]). The electric power transmitted over AC transmission lines is exactly the same as the power we use every day from AC outlets, but at a much higher voltage. Over the past 40 years HVDC transmission lines have been constructed that offer significant electrical, economic, and environmental advantages over AC transmission lines for long distances. Direct Current (DC) transmission is especially suited for integrating and transporting power generated by various renewable energy sources. Unlike an AC transmission line, the voltage and current on a DC transmission line are not time varying, meaning they do not change direction as energy is transmitted.

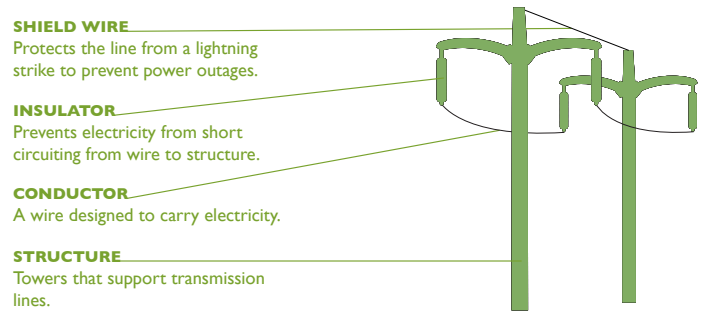
THE BENEFITS OF HVDC

MORE EFFICIENT: Over long distances, HVDC transmission can move more power with less losses versus an equivalent AC transmission line.

LOWER COST: Higher efficiency means a lower transmission cost, helping renewables compete against other power sources.

IMPROVED RELIABILITY: HVDC transmission can enhance system stability, allow the operator complete control over power flow, and facilitate the integration of wind from different resource areas.

SMALLER FOOTPRINT: HVDC transmission lines require narrower right-of-way footprints and smaller structures than equivalent AC transmission lines.



A DC transmission line has two conductor bundles called "poles." Conductors are the wires that hang from the towers and are often bundled in groups of two or three. Like a car battery, the two bundles of DC conductors have opposite polarity, one positive and one negative. The voltage of a DC transmission line, therefore, is usually referred to as ± (plus-minus) voltage. For example, a 500 kilovolt (kV) DC transmission facility would be referred to as a ± 500 kV DC transmission line.

DIRECT CURRENT (DC) The flow of electric charge is only in one direction.
ALTERNATING CURRENT (AC) The movement of electric charge that periodically reverses direction.

CURRENTLY, THERE ARE MORE THAN 20 HVDC TRANSMISSION FACILITIES IN THE UNITED STATES AND MORE THAN 35 ACROSS THE NORTH AMERICAN GRID.

DC electricity is the steady movement of electrons from an area of negative (−) charge to an area of positive (+) charge and therefore has a frequency of 0 Hz. The first commercial electric power system built by Thomas Edison in the late nineteenth century carried DC electricity, but given some early advantages, AC power eventually became the primary power system in the United States. Some of these advantages are no longer applicable (e.g., technology has advanced to allow better conversion from AC to DC), and DC transmission is the preferred solution for moving large amounts of renewable power over long distances. Currently, there are more than 20 HVDC transmission facilities in the United States and more than 35 across the North American grid (as indicated on the map to the right).

HVDC FACILITIES ACROSS NORTH AMERICA

STATIC ELECTRIC AND MAGNETIC FIELDS

DC electricity produces static electric and magnetic fields, but these fields have very different properties from AC Electric Magnetic Fields (EMF*). For example, because the EMF from AC lines are time varying, they can induce currents and voltages in nearby conductive objects. Since DC electricity does not vary over time and is static, the electric and magnetic fields from DC lines do not induce currents and voltages. Table 1 lists both natural and man-made sources of static fields. Table 2 lists the levels of static fields associated with common sources—such as cathode tube television sets, MRI machines, and stereo headphones—and illustrates that the levels of static electric and magnetic fields from DC transmission lines are lower than or in the range of natural sources of these fields.

*The abbreviation EMF is commonly used to refer to electric and magnetic fields from sources of AC electricity, not DC electricity.

TABLE 1: EXAMPLES OF NATURAL AND MAN-MAN SOURCES OF STATIC ELECTRIC AND MAGNETIC FIELDS

	NATURAL SOURCES	MAN-MADE SOURCES
ELECTRIC FIELDS	Static electricity Static cling Charges built-up in thunderstorm clouds	Electrified railways Televisions with cathode ray tubes
MAGNETIC FIELDS	The Earth	Permanent magnets Battery-powered appliances MRI machines Electrified railways

TABLE 2: STATIC ELECTRIC AND MAGNETIC FIELD LEVELS CLOSE TO COMMON SOURCES

ELECTRIC FIELDS	
Source	**Electric Field Level**
Friction from walking across carpet (at body surface)	Up to 500 kV/m
Computer screen (at 30 centimeters)	10-20 kV/m
± 500 kV DC transmission line (standing beneath conductors)	30 kV/m
MAGNETIC FIELDS	
Source	**Magnetic Field Level**
MRI machines	15,000,000 - 40,000,000 mG
Battery-operated appliances	3,000 - 10,000 mG
Electrified railways	<10,000 mG
The Earth	300 - 700 mG
± 500 kV DC transmission line (standing beneath conductors)	300 - 600 mG

*The Earth's static magnetic field level depends on location; the highest values are found at the magnetic north and south poles and the lowest values are found near the equator.
** mG: a milligauss is 1/1000th of a Gauss, which is a measure of the magnetic field. A typical refrigerator magnet will produce about 50 Gauss, or 50,000 mG.
*** kV: a Kilovolt is 1000 volts.

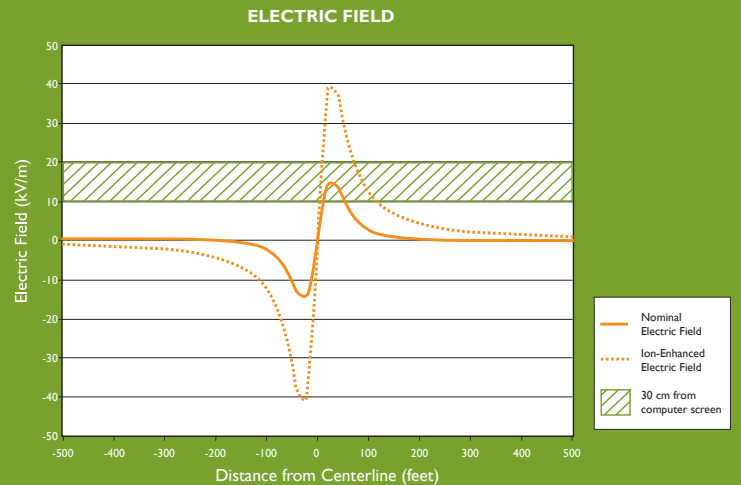
SINCE DC ELECTRICITY DOES NOT VARY OVER TIME AND IS STATIC, THE ELECTRIC AND MAGNETIC FIELDS FROM DC LINES DO NOT INDUCE CURRENTS AND VOLTAGES.

STATIC ELECTRIC FIELDS FROM DC TRANSMISSION LINES HAVE LITTLE INFLUENCE ON THE STATIC ELECTRIC FIELD LEVELS WITHIN NEARBY BUILDINGS.

STATIC ELECTRIC FIELDS

Static electric fields occur as a result of voltage and are produced by a DC transmission line's conductors and by airborne charge. Airborne charge includes air ions (air molecules that have gained or lost charges) and particles in the air that have become charged from collisions with air ions. This airborne charge is collectively referred to as space charge. Trees, bushes, and any conducting building material block static electric fields. Therefore, static electric fields from DC transmission lines have little influence on the static electric field levels within nearby buildings adjacent to the right-of-way.

A common, natural source of static electric fields is "static electricity," which results from a difference in electric potential between two points that can result in a discharge of energy. Well-known sources include the charge on the body produced by shuffling across a carpet and the strong electric fields produced by the "static cling" of clothing. Other common sources include the charges built-up in thunderstorm clouds and on blowing dust. The static electric field levels measured directly under DC lines fall in the range of the levels produced by these common sources.



The graph above shows both the nominal electric field and ion-enhanced electric field in fair weather under a ±600 kV transmission line (similar to the lines proposed by Clean Line Energy) from the center of the line out to a lateral distance of 500 feet on each side of the transmission line. As can be seen on this plot, the electric field is highest directly under the conductors and rapidly diminishes with distance from the line. The plot illustrates that the electric field derives both from the voltage on the conductors (the nominal field in the plot) and from charges on air molecules (air ions). The contribution of air ions to the total electric field will be variable depending on weather conditions. (Source: POWER Engineers, Inc. for Clean Line Energy Partners LLC)

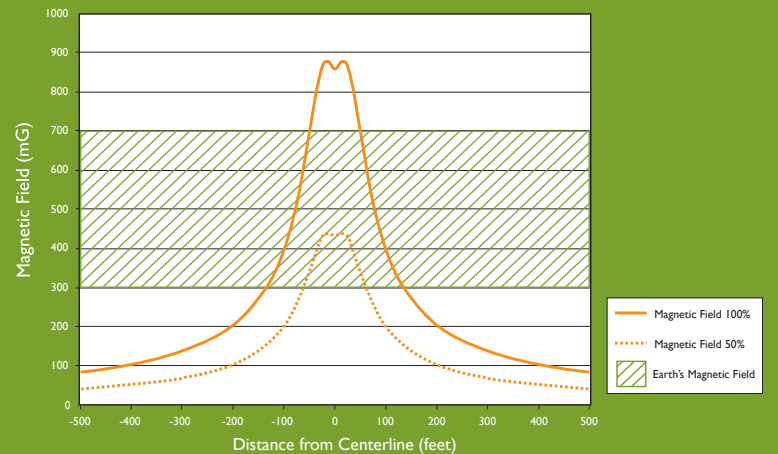
THE STATIC MAGNETIC FIELD LEVELS BELOW OVERHEAD DC TRANSMISSION LINES ARE SIMILAR TO OR LESS THAN THE STATIC MAGNETIC FIELD OF THE EARTH.

STATIC MAGNETIC FIELDS

Static magnetic fields are created by the flow of DC electricity. The major source of static magnetic fields in our environment is the steady flow of currents deep in the Earth's outer liquid core and from metallic elements in the Earth's crust. This constant and ever-present field is what causes compass needles to orient in a north-south direction. Depending on the orientation of a DC transmission line, the magnetic field from the transmission line can either increase or decrease the Earth's DC magnetic field.

Other common sources of static magnetic fields include permanent magnets (which are found in appliances, toys, and medical devices), battery-powered appliances, magnetic resonance imaging (MRI) machines, some electrified railway systems, and certain industrial processes. MRI machines produce static magnetic fields in the range of 15-40 million milligauss (mG), while the Earth's static magnetic field ranges from 300-700 mG (Table 3). The static magnetic field levels below overhead DC transmission lines are similar to or less than the static magnetic field of the Earth. Unlike static electric fields, static magnetic fields are not blocked by most objects.

MAGNETIC FIELD



This graph shows the magnetic field under a ±600 kV transmission line (similar to the lines proposed by Clean Line Energy) from the center line out to a lateral distance of 500 feet on each side of the transmission line with full load current (100% load producing highest magnetic field) flowing in the pole conductors. At other times the load carried will be less (50% load) and will produce a proportionally lower magnetic field. Similar to electric fields, the strength of the magnetic field diminishes very quickly moving from directly under the conductors to the edge of the right-of-way and beyond. The magnetic fields shown in this graph are on the same order of magnitude as Earth's naturally occurring magnetic field (about 300 mG to 700 mG). Outside of the right-of-way, magnetic field strengths will be lower than the fields presented everywhere and everyday due to the Earth's own magnetic fields. The static magnetic field level associated with DC transmission lines and the Earth's magnetic field are far below limits for human exposure as recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[1] and the International Commission for Electromagnetic Safety (ICES)[2].

[1]The ICNIRP is a body of independent scientific experts covering Epidemiology, Biology, Dosimetry and Optical Radiation. This expertise is brought to bear on addressing the important issues of possible adverse effects on human health of exposure to non-ionising radiation.
[2]The ICES is a non-profit organization that promotes research to protect public health from electromagnetic fields and develops the scientific basis and strategies for assessment, prevention, management and communication of risk.
(Source: POWER Engineers, Inc. for Clean Line Energy Partners LLC)

REVIEWS AND STANDARDS FOR EXPOSURE TO STATIC FIELDS

Like the EMF associated with AC power, questions have been raised about the possibility that static fields affect our health. The vast majority of research has focused on the possibility that strong static field levels might have biological effects, either beneficial (i.e., therapeutic) or adverse. There is less interest in weak static field levels in the range of those produced by DC transmission lines because similar levels occur naturally. This research has been reviewed and summarized by the following organizations:

- International Agency for Research on Cancer (IARC) in 2002
- National Radiological Protection Board of Great Britain (NRPB) in 2004
- World Health Organization (WHO) in 2006
- International Commission on Electromagnetic Safety (ICES) in 2002 and 2007
- International Commission on Non-ionizing Radiation Protection (ICNIRP) in 2009

All of these scientific panels concluded that the current body of research does not indicate that strong static magnetic fields cause long-term health effects such as cancer. Additional research is being conducted on occupational exposures in locations where work is performed in very high field levels such as certain industrial sites and near MRI units. Movement within very strong static magnetic fields of experimental MRI scanners is known, however, to cause immediate and reversible responses that are not life threatening–e.g., nausea and visual sensations. Exposure limits have been developed by the ICNIRP and ICES to avoid these effects (Table 3).

The static magnetic field levels associated with DC transmission lines and the Earth's natural magnetic field are far below these limits for human exposure.

TABLE 3: RECOMMENDED LIMITS FOR EXPOSURE TO STATIC MAGNETIC FIELDS

	ICNIRP[1]	ICES[2]
General Public	4,000,000 mG	1,180,000 mG
Workers	20,000,000 mG	3,530,000 mG

Exposure to static magnetic fields standing under a ±600 Kv HVDC transmission is less than 900mG.

[1] International Commission on Non-ionizing Radiation Protection (ICNIRP). Guidelines On Limits of Exposure to Static Magnetic Fields. Health Physics 96:504-514, 2009.
[2] <0.153Hz, International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz C95. 6-2002. Piscataway, NJ: IEEE, 2002. Reaffirmed 2007.

THE CURRENT BODY OF RESEARCH DOES NOT INDICATE THAT STRONG STATIC MAGNETIC FIELDS CAUSE LONG-TERM HEALTH EFFECTS.

Like static magnetic fields, static electric fields do not induce voltages and currents in the body. Unlike magnetic fields, static electric fields do not enter the body. High levels of static fields can sometimes be perceived by the movement of body hair and cause effects similar to those associated with static electricity. Clean Line Energy follows recommendations of the Health Protection Agency of Great Britain (formerly the NRPB) to minimize sensations associated with static electric fields.

CORONA PHENOMENA

Corona refers to the partial electrical breakdown by the electric field of the air surrounding points on the conductor surface of transmission lines. This breakdown results in the release of small amounts of energy that may be detected near the line as audible noise and 'static' on radio and television receivers. Clean Line projects will be designed to meet U.S. Environmental Protection Agency (audible noise)[1] and IEEE (radio/TV noise)[2] guidelines.

Corona also creates air ions, which are molecules that have temporarily gained or lost electrons. Air ions occur as a result of geologic, atmospheric, weather-related, and combustion phenomena, e.g., flames. Most air ions from DC transmission lines are carried to the ground or the opposite polarity conductor, but some remain in the air for seconds before contacting an opposite charge or transferring charge to small aerosol particles. Air ions and charges on aerosols collectively are called "space charge," and their presence adds to the DC static electric field created by the conductors. Space charge has been studied for over one hundred years and no health agency has confirmed any health risk of this natural phenomenon or proposed health-based exposure limits.

1 U.S. Environmental Protection Agency (USEPA). Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. Office of Noise Abatement and Control, March 1974.
2 IEEE Committee Report. Radio Noise Design Guide for High Voltage Transmission Lines. IEEE Transactions on Power Apparatus and Systems, PAS-90: 833-842, 1971.

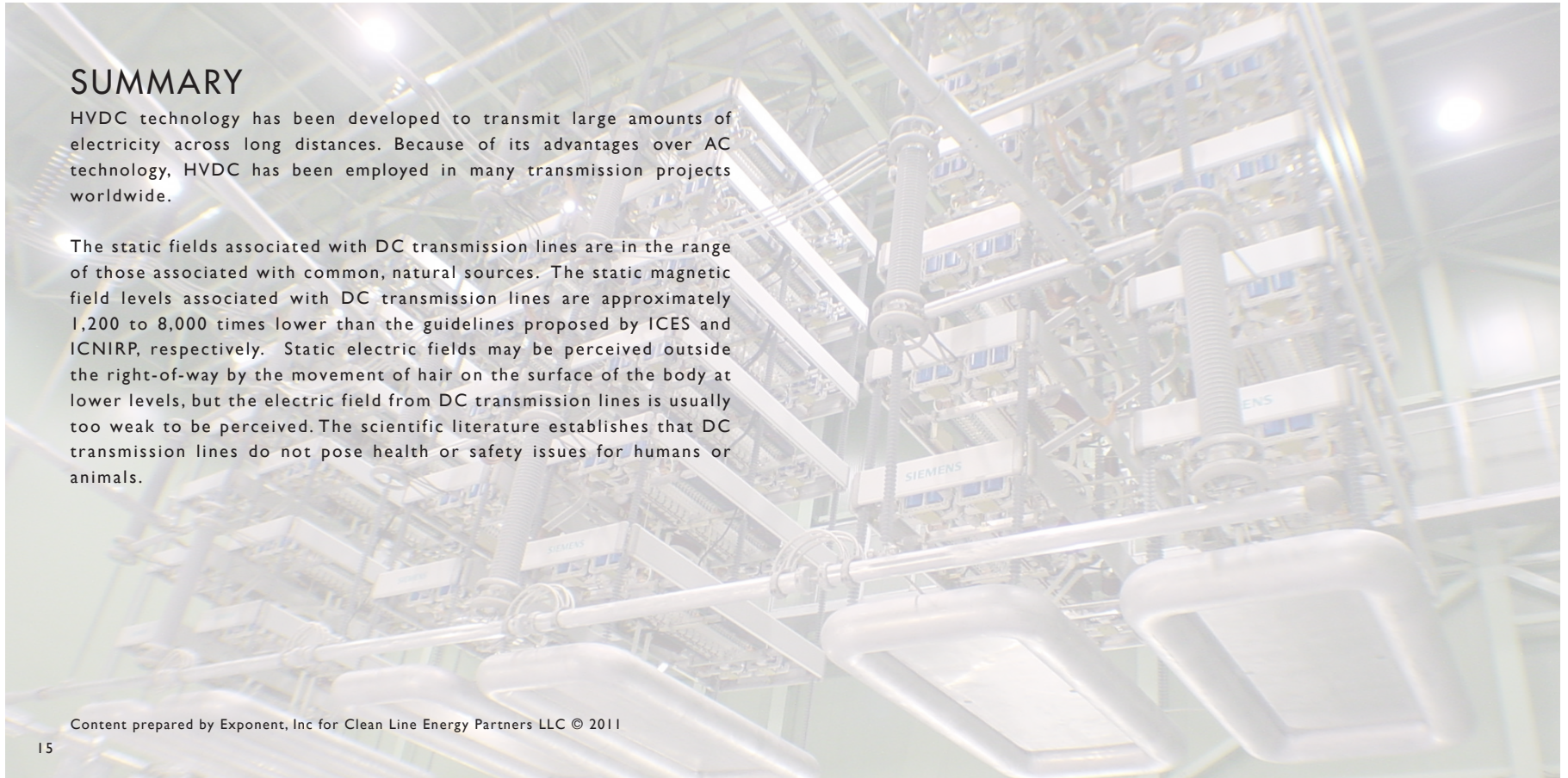
ELECTRONIC DEVICES

The static fields of DC transmission lines are too weak to affect the operation of implanted medical devices such as cardiac pacemakers. Like AC transmission lines, the corona on DC lines can produce AM radio and TV audio signal interference within about 100 feet of the lines. The possibility of interference to cell phones, GPS receivers, etc., is unlikely.

FARM AND RANCHING OPERATIONS

Studies performed for a federal agency on the effects of a DC transmission line reported that the line did not affect crops, vegetation, or nearby wildlife, nor were the fields perceived by persons walking on the right-of-way.[1] Another study conducted by Oregon State University reported no differences between cattle and crops raised under a ±500 kV DC transmission line and those raised in a control location away from the line[2]. A study of over 500 herds of dairy cattle in Minnesota reported that multiple indicators of herd health including milk production per cow, reproductive efficiency, and milk fat content did not differ in the periods before and after a DC line was energized, nor did they differ if a herd was close to or far from the DC line[3].

1 Griffith DB. Selected Biological Parameters Associated with a ±400 kV DC Transmission Line in Oregon. A Report by the Western Interstate Commission for Higher Education for the Bonneville Power Administration, Portland, OR. 1977; Lee JM, Jr. and Griffith DB. Transmission Line Audible Noise and Wildlife. In JL Fletcher and RG Busnel (eds). Effects of Noise on Wildlife. New York: Academic Press, 1978
2 Raleigh RJ. Joint HVDC Agricultural Study: Final Report. Oregon State University. Report for Boneville Power Administration, 1988.
3 Martin FB, Bender A, Steurnagel G, Robinson RA, et al. Epidemiologic study of Holstein dairy cow performance and reproduction near a high-voltage direct-current powerline. J Toxicol Environ Health 19:303-324; 1986.



SUMMARY

HVDC technology has been developed to transmit large amounts of electricity across long distances. Because of its advantages over AC technology, HVDC has been employed in many transmission projects worldwide.

The static fields associated with DC transmission lines are in the range of those associated with common, natural sources. The static magnetic field levels associated with DC transmission lines are approximately 1,200 to 8,000 times lower than the guidelines proposed by ICES and ICNIRP, respectively. Static electric fields may be perceived outside the right-of-way by the movement of hair on the surface of the body at lower levels, but the electric field from DC transmission lines is usually too weak to be perceived. The scientific literature establishes that DC transmission lines do not pose health or safety issues for humans or animals.

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ABOUT CLEAN LINE ENERGY

AN EFFECTIVE SOLUTION TO THE NATION'S TRANSMISSION CHALLENGE REQUIRES THE APPROPRIATE TECHNOLOGY AND THE RIGHT PROJECTS. CLEAN LINE IS DEVELOPING A PORTFOLIO OF PROJECTS THAT HAVE A SIMILAR, COMPELLING RATIONALE – THE DELIVERY OF THOUSANDS OF MEGAWATTS OF RENEWABLE POWER FROM THE WINDIEST AREAS OF THE UNITED STATES TO AREAS THAT HAVE A DEMAND FOR CLEAN ENERGY BUT LACK ACCESS TO CLEAN ENERGY RESOURCES.

THESE PROJECTS WILL HELP MAKE POSSIBLE:

- CREATION OF THOUSANDS OF CONSTRUCTION AND PERMANENT JOBS
- BILLIONS OF DOLLARS OF INVESTMENTS IN NEW RENEWABLE ENERGY PROJECTS
- RURAL ECONOMIC DEVELOPMENT
- THE REDUCTION OF CARBON POLLUTION BY MILLIONS OF TONS
- INCENTIVES TO MANUFACTURE WIND TURBINES AND COMPONENTS
- PROPERTY TAX REVENUE FOR LOCAL COMMUNITIES
- LANDOWNER ROYALTIES

CLEAN LINE'S MANAGEMENT TEAM INCLUDES HIGHLY REGARDED PROFESSIONALS IN THE ELECTRIC ENERGY INDUSTRY. COLLECTIVELY, THE CLEAN LINE TEAM HAS ORGANIZED THE FINANCING OF BILLIONS OF DOLLARS OF PROJECTS AND MANAGED THE DEVELOPMENT AND CONSTRUCTION OF THOUSANDS OF MEGAWATTS OF GENERATION AND TRANSMISSION LINES.

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