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Edited by Gregory K. Ingram and Yu-Hung Hong

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Alternative Energy Sources and Land Use

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Judd M. Schechtman, and Mathias Mayr

The public imagination has turned to renewable energy as a solution to the interlinked problems of volatile energy prices, insecure fossil fuel supplies, and global climate change. What are the implications for land policy of scaling up renewable energy use? This chapter examines the land intensiveness of energy production, the land requirements for meeting a significant portion of energy demand, and the constraints on land availability for various resource types. Many renewable energy sources will necessarily be located distant from the centers of energy demand, requiring expanded electricity transmission networks. Both recent experience and emerging proposals confirm that these networks need to grow and become more interconnected. Where to locate energy facilities and transmission lines has been a source of controversy over the past 30 years. We examine locational conflicts during this time and the state of siting policy today.

How Land Intensive Is Energy Production?

The basic physics of energy production determine many of its impacts on land policy. Fossil fuels, geothermal energy, and nuclear power exploit highly concentrated, mined resources and convert them to useful energy in power plants or refineries. The land requirements of these energy sources include the footprints of mines and drilling sites, associated support infrastructure, transportation routes from the extraction site to the conversion site, the footprint of the conversion site, and the footprint of any needed waste depository. Solar, wind, and biomass energy additionally require substantial amounts of land to collect highly diffuse, ambient energy from the sun or wind. Land intensity can be measured using the land area (km^2) required to deliver a standard amount of economically useful energy (terrawatthours per year, or TWh-yr). The TWh-yr unit does not imply only electricity, because gaseous and liquid energy carriers are also economically valuable.

McDonald et al. (2009) provide a current, careful estimate of the ranges of land use intensities (in km^2/TWh-yr) associated with various energy sources based on the expected state of technology in the year 2030, listed in order of increasing land intensity: nuclear power (1–3), geothermal (1–14), coal (3–17), solar thermal (10–20), natural gas (1–36), solar photovoltaic (21–53), petroleum (1–88), hydropower (16–92), wind (65–79), sugarcane ethanol (220–350), corn ethanol (320–375), cellulosic ethanol (120–750), electricity from biomass (433–654), and soy biodiesel (780–1,000). These ranges cover McDonald et al.'s most compact and least compact estimates and include land needed for resource extraction, processing, conversion, and waste storage.

Given the finite land area on earth and the need to reserve some land for food, fiber, recreation, and biodiversity, certain resources may be implausibly land intensive. Melillo et al. (2009) identify key quantities: the land area on earth is approximately 133 million km^2; natural forests total about 34 million km^2; and the land area already co-opted for human use is about 42 million km^2, of which about 16 million km^2 are in crops, 26 million km^2 are in pasture, and much less than 1 million km^2 encompass human settlements.[1] The 2010 global demand for energy is projected to be 148,922 TWh-yr, increasing to 198,743 TWh-yr in 2030 (EIA 2009a). Although this chapter focuses on 2010 energy demand because it is a more familiar number, it is important to remember that energy demand will continue to grow as the global population grows and people become more affluent.

Figure 5.1 summarizes a thought experiment that estimates the land requirements by energy resource type to meet 10 percent and 100 percent of 2010 global energy demand, based on current conversion technologies. This hypothetical snapshot reveals that the land use differences among resource types vary by orders of magnitude. Category 1 consists of nuclear power, geothermal, coal, solar thermal, and natural gas, none of which is land intensive, even at scale. Category 2 includes solar photovoltaics, petroleum, hydropower, and wind, all of which are land intensive when implemented on a large scale, an impact that is even more significant because these resources are unevenly spread across the landscape. Cate-

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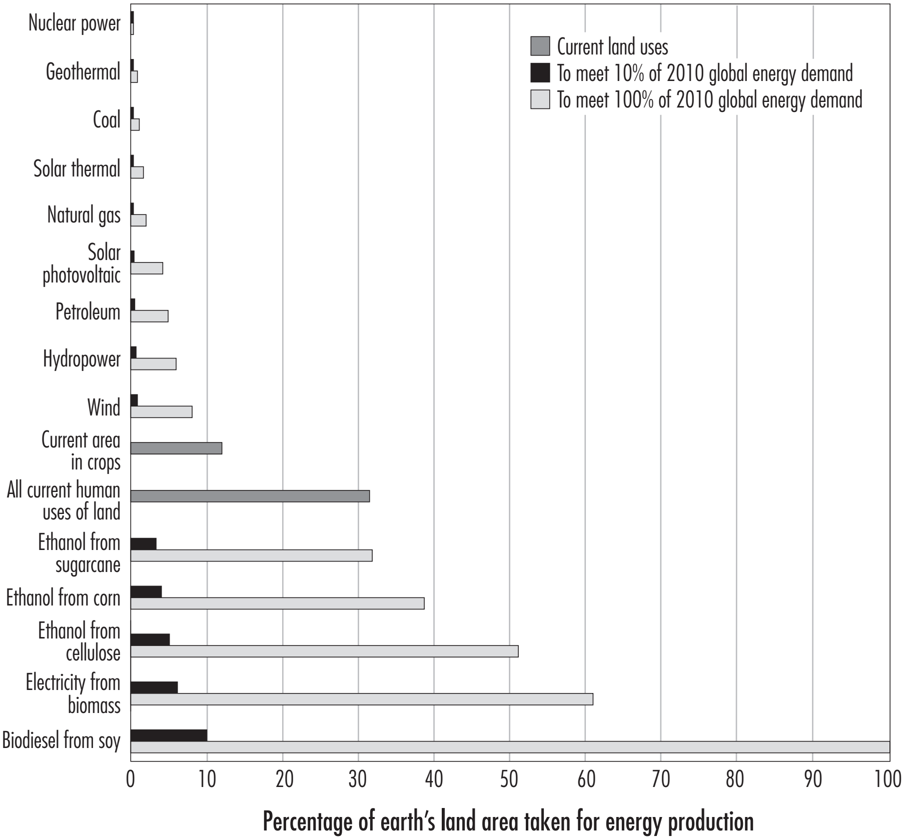
[1] Remarkably, there is disagreement about the land area on earth, with official estimates ranging from 130 million km^2 (UNEP 2009) to 152 million km^2 (Watson et al. 2000). Here we use a lower-end estimate of 133 million km^2 that has undergone peer review (Melillo et al. 2009). Disparities are also evident in estimates of specific land uses.

Figure 5.1
Land Requirements of Alternative Energy Sources



Sources: Land intensiveness data from McDonald et al. (2009); land area data from Melillo et al. (2009); global energy demand data from EIA (2009a).

gory 3 includes all the biofuels, which are so land intensive that they can never become dominant energy sources, although they may capture niches.

This thought experiment ignores several important considerations, including the geographic variation in land suitability and energy resource intensity, the potential for conflicts and complementarities among land uses, the distances between the locations of energy supply and demand, and the need to supply energy in specific forms for specific end uses. Almost all of these factors increase, rather than decrease, the land use requirements of energy production, so the real impacts on land policy are understated.

CATEGORY 1: GEOTHERMAL AND SOLAR THERMAL

Two renewable energy resources belong to the same small-footprint impact category as nuclear power, coal, and natural gas. Geothermal fits in this category because it essentially uses gas- and oil-drilling technology to harvest deeply buried hot water, and, like fossil fuels, it is located in abundance in only a few locations (EIA 2010b). A major commitment to research, thus far lacking around the world, could greatly expand the range of suitable locations (Tester et al. 2006). The land policy issues associated with geothermal are similar to those related to conventional energy resources.

The more interesting case for land policy is solar thermal. There are two major types of solar thermal systems: low-temperature distributed systems for heating and hot water, and centralized high-temperature systems that use concentrated sunlight to generate heat and electricity (Randolph and Masters 2008).

Low-temperature systems are usually confined to rooftops and are ubiquitous in Australia, China, Israel, and the far southern and western United States, where reliable sunshine is available (EIA 2010b). They appear in smaller numbers on rooftops all around the world, even in the dark and cloudy corners of Alaska and northern Europe. One important virtue of low-temperature solar thermal systems is that they closely match the low-temperature quality of the distributed solar resource with categories of energy demand that require low temperatures: space and water heating. An important weakness is that the solar collector must be located adjacent to its point of use, because it is uneconomic to transport low-temperature heat long distances. Low-temperature systems can fully satisfy local demands for heating and hot water in rural and suburban contexts, but there is not enough rooftop area available in dense cities to serve everyone's heating and hot water needs. These low-temperature systems thus have category 2 land intensity characteristics.

High-temperature systems, by contrast, belong in category 1. Although they must be located in hot, dry, sunny locations, their footprints are small. Typical configurations include (1) power towers, in which a sea of tracking mirrors on the ground focuses sunlight intensely on a single point atop each tower; and (2) trough fields, in which lines of parabola-shaped reflectors focus sunlight in a strip along the pipe located atop each trough (EIA 2010b). In both cases, the reflected sunlight generates high temperatures that can boil a heat-transfer fluid such as water and drive Stirling engines, steam turbines, and industrial processes. This allows the production of solar thermal electricity, among other products.

The challenge with high-temperature systems is similar to that with natural gas, coal, oil, and geothermal resources: their economics require investors to seek out locations with the most concentrated resources. Thus, we see high-temperature solar power plants in the southwestern United States and Spain, as well as proposals for new plants in Saharan Africa and other low-latitude desert locations.

At a large scale, will high-temperature solar thermal systems fit within the footprint of available desert areas? Multiplying the midpoint land intensity value for solar thermal of 15.3 km^2/TWh-yr (McDonald et al. 2009) by 100 percent of the current global demand for energy of 148,922 TWh-yr (EIA 2009a) yields 2,278,507 km^2. This area easily fits within the 15,073,800 km^2 of major subtropical deserts on earth, which include Africa's Sahara (9,065,000 km^2) and Kalahari (569,800 km^2); the Middle East's Arabian (2,590,000 km^2); India's Thar (453,250 km^2); Australia's Gibson, Great Sandy, Great Victoria, Simpson, and Sturt Stony (1,491,840 km^2); and North America's Mojave (139,860 km^2), Sonoran (310,800 km^2), and Chihuahuan (453,250 km^2) (Infoplease 2007). Dedicating 15 percent of the world's subtropical deserts to energy production would be a civilization-changing act similar in scale to launching the agricultural revolution, but it would play out on some of the earth's least desirable land, it would be dispersed across several continents, and its pace could be slow enough to allow adaptation to address local concerns.

The challenge of delivering electricity generated in these remote locations to final consumers is substantial. We will return to this issue later in the chapter.

CATEGORY 2: SOLAR PHOTOVOLTAICS AND WIND

The medium-footprint land impact category is a source of many hopes and fears. It includes petroleum, from which the world is trying to wean itself in coming decades; hydropower, which is approaching its global limits; and solar photovoltaics and wind, two technologies that are becoming ubiquitous. We focus on the land impacts of the last two technologies here because their use is growing rapidly worldwide.

Photovoltaic energy production turns sunlight into electricity using semiconductor technologies that operate at low conversion efficiencies currently ranging from 8 percent for thin-film amorphous silicon to 19 percent for single-crystal silicon, typically without concentrating the sunlight first (EIA 2010c). Photovoltaic cells can operate using both direct and diffuse sunlight, making them useful in a variety of nondesert locations. They produce direct current (DC) electricity, which typically needs to be converted to alternating current (AC) power before use, and the inverters and associated losses lead to a derate factor on the order of 77 percent when calculating a system's AC power output (NREL 2010b). Photovoltaic cells are modular, so economies of scale come from mass production rather than unit size. This makes them good candidates for distributed generation at off-grid sites such as microwave towers and for local, grid-connected applications such as rooftops.

Although prices have decreased by an order of magnitude since the 1980s, photovoltaics are still an expensive way to generate electricity, costing roughly three times as much on a cents-per-kilowatt-hour basis as standard electricity from the U.S. grid (Solarbuzz 2010). Photovoltaic cost reductions since 2000 have been mostly due to improved rest-of-system prices, but since 2007 prices for the modules themselves have dropped more rapidly (Wiser et al. 2009). Prices exclusive of subsidies are lower in Germany and Japan than in the United States, largely because of greater domestic production capacity (Wiser et al. 2009).

For land policy, the scale question is very important, because more solar photovoltaic installations will appear as system costs continue to decrease and efficiencies continue to improve. The first hope expressed by solar advocates is that households could become energy self-sufficient by installing rooftop photovoltaic arrays. Table 5.1 shows that this can work only under fairly restrictive conditions. Household self-sufficiency depends on the balance between household energy demand and supply, and supply is a function of the available roof area, the technology, and the intensity of the solar resource.

Table 5.1 summarizes scenarios generated using the PVWatts simulation model (NREL 2010b) on fixed-tilt arrays with a sunlight energy conversion efficiency of 11 percent and a derating factor of 77 percent for a variety of locations from Anchorage, Alaska, to Phoenix, Arizona. Household energy usage typical of hyperefficient Japan is contrasted with usage typical of the more profligate United States, Canada, and Australia. Additionally, the smaller housing units typical of Japan and Europe are contrasted with the larger units found in North America and Australia. Finally, the scenarios include height factors of 1 (single-story buildings) and 2 (two-story buildings) to reflect different building styles. The results show that only single-story homes are ever likely to achieve energy self-sufficiency, unless they implausibly combine Japanese energy efficiency levels with North American housing sizes. Single-story, North American–size homes with North American energy efficiency levels need to be located in very sunny places in order to be self-sufficient. This outcome hints at the challenge of using photovoltaics in an urban context: buildings with two or more stories are quite common in cities, and they do not have enough roof area for the required amount of solar cells.

Based purely on these physical considerations—before even worrying about economic feasibility—it seems clear that partial self-sufficiency is the best that most North American housing units outside the Sun Belt can expect until conversion efficiencies double or triple. This implies a need to stay connected to the electric grid. Once the continued need for the grid is established, it becomes possible to consider other uses of photovoltaics, such as remote, large-scale, ground-based arrays and utility pole–top modules. Some 5.5 million km^2 of land area would be needed to supply 100 percent of current energy demand with solar photovoltaics. This amount of land would easily fit within the desert regions of the world.

Wind needs twice as much land area to generate the same amount of energy as solar photovoltaics and varies even more by location. The largest areas with good wind resources in the United States lie in the sparsely populated Great Plains and in pockets along the mountain spines of the East and West Coasts. In China, the best wind resources are similarly located far away from the population centers. Even in the compact United Kingdom, the best resources are in relatively remote Cornwall, Wales, and Scotland. A careful study of the U.S. land area having "good" wind resources identified 2,571,180 km^2 spread across the

Table 5.1
Percentage of Household Energy Needs Potentially Met by Rooftop Solar Photovoltaics

	Household Energy Use (kWh-yr)	**Similar to Japan (12,000)**				**Similar to U.S., Canada, Australia (28,000)**			
	Floor Area (m^2)	**Similar to Japan, Europe (100)**		**Similar to U.S., Canada, Australia (200)**		**Similar to Japan, Europe (100)**		**Similar to U.S., Canada, Australia (200)**	
	Height Factor (floors)	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Solar Energy Produced (kWh-yr/m^2)	Similar to Anchorage, London, Vienna (90)	75	38	150	75	32	16	64	32
	Similar to New York, Tokyo (120)	100	50	200	100	43	21	86	43
	Similar to Madrid, Nairobi, Sydney (150)	125	63	250	125	54	27	107	54
	Similar to Adelaide, Addis Ababa, Phoenix (180)	150	75	300	150	64	32	129	64

Note: Assumes that array tilt is optimized for location.
Sources: Solar energy production from NREL (2010b); household energy use from Zhang (2004) and EIA (2009b); floor area from Demographia (2010) and EIA (2009b).

48 contiguous states (USDOE 2010). Of that amount, 479,391 km^2 was excluded because it lies in protected wilderness areas, parks, urban areas, valued water features, or locations with high slopes, leaving a total of 2,091,789 km^2 available for potential exploitation. With current technology, that land area could potentially deliver 36,920 TWh-yr of energy (USDOE 2010), equivalent to 125 percent of total projected 2010 U.S. energy consumption (EIA 2009a). Unlike land-rich North America, compact Europe is unlikely to achieve energy self-sufficiency using land-based wind resources, even though several countries have successfully installed thousands of wind turbines. The Europeans have led the push for offshore wind that is now beginning to influence U.S. policy making.

Siting conflicts for both onshore and offshore wind installations have increased as the technology has been deployed around the world. In a special issue of *Land Policy* devoted to European wind farms, researchers note that locally owned wind farms are easier to site than those owned by remote investors; the aesthetic burdens are becoming increasingly inequitable as the technology grows in scale; the tendency is to move offshore in the hope of reducing siting conflicts; and offshore seascapes are not tabula rasa, but have cultural importance that contributes to the persistence of siting difficulties (Nadaï 2010). Meyerhoff, Ohl, and Hartje (2010) confirm that citizens experience negative landscape externalities from wind power installations. However, a multisite, hedonic study of the effect of 24 U.S. wind power installations on nearby residential property values found no significant effect on home prices (Hoen et al. 2009). Also, unlike most other renewable energy technologies, wind farms can serve multiple purposes. They are widely used for grazing cattle, for example.

In sum, rooftop solar panels can make a contribution to the global energy supply, but both solar and wind technologies will more often be deployed in remote locations where the resources are better, more land is available, and siting conflicts are less severe. Getting the energy back to consumers is the looming challenge.

CATEGORY 3: BIOENERGY

As a focus of hyperbole and political gamesmanship, bioenergy is preeminent, even if physical limits prevent it from becoming a globally dominant energy solution. Farmers already know how to grow corn, sugarcane, rapeseed, and other bioenergy crops, and refiners already know how to blend ethanol and biodiesel with gasoline and petro-diesel fuels to distribute these resources within the energy economy. Thus, governments using relatively simple subsidy policies can drive significant short-run increases in bioenergy production. At issue are the unintended consequences of pursuing this resource on a large scale.

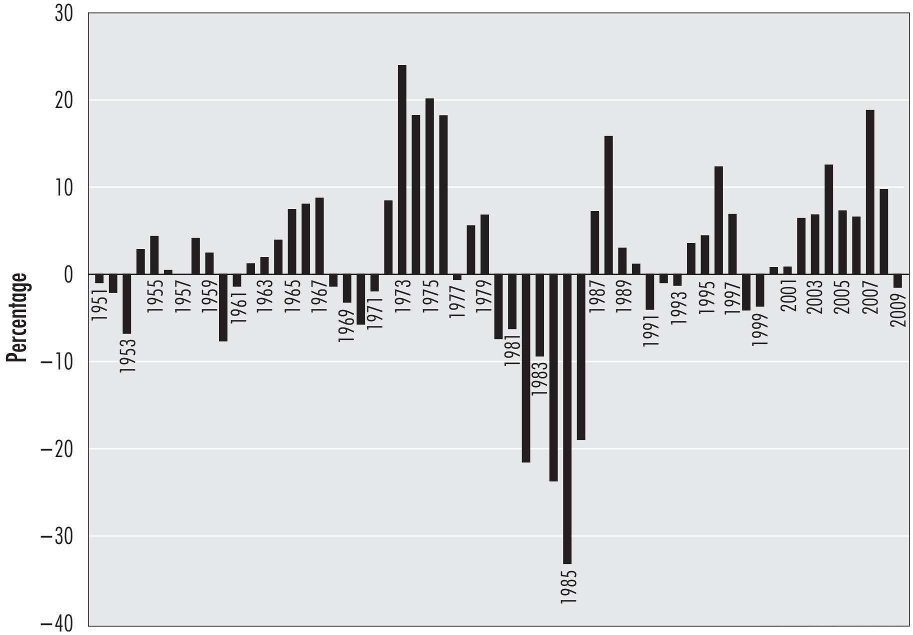
A primary concern is whether energy crops will displace food crops, forests, or something else. Global land market modeling suggests that all three categories will be significantly affected. An increase of one billion gallons in U.S. ethanol demand (a 20 percent increase over 2006 sales) would lead to global losses of pastureland (e.g., 0.53 percent of current U.S. pastureland and 0.17 percent of current Brazilian pastureland) and forest cover (e.g., 0.35 percent of U.S. forests and 0.16 percent of Brazilian forests) (Keeney and Hertel 2009). A computable general equilibrium (CGE) model of the European Union Biofuels Directive found similar global impacts on land use (Banse et al. 2008). Environmental scientists have undermined the whole climate change–based rationale for switching to bioenergy by showing that when bioenergy crops displace forests, they incur carbon debts so large that they never reach carbon neutrality (Fargione et al. 2008; Melillo et al. 2009; Searchinger et al. 2008). Bioenergy crops also have the unfortunate effect on the earth's grand nutrient cycles of overloading the nitrogen cycle while attempting to manage the carbon cycle (Ayres, Schlesinger, and Socolow 1994; Melillo et al. 2009) and of commandeering scarce freshwater resources, so that, for example, meeting China's bioenergy target will require dedication of the equivalent of the entire flow of the Yellow River (Yang, Zhou, and Liu 2009).

The largest concern about biofuels is the possibility of conflict with food production. Prospective studies of bioenergy policies predict higher food prices and increasing agricultural land values in Europe (Banse et al. 2008), the United States (Johansson and Azar 2007), and China (Yang, Zhou, and Liu 2009), as well as worldwide (Birur, Hertel, and Tyner 2007; Runge and Senauer 2007).

Retrospective studies of the U.S. experience following its 2005 bioenergy legislation are more equivocal. Abbott, Hurt, and Tyner (2009) identify the key drivers of U.S. grain prices as follows: annual variations in crop production due to weather and expected prices; variations in demand due to price response and the vagaries of downstream meat production (which consumes grains); the exchange rate of the dollar and related world macroeconomic factors; and the energy-agriculture linkage. These factors conspired to drive food prices to record high levels in 2008, although they have since dropped. Abbott, Hurt, and Tyner (2009) found strong links between ethanol and corn prices beginning in 2006, but only weak links between ethanol and fluctuating gasoline prices. An analysis published at the height of the food price bubble predicted that biofuels would cause food prices to rise 23–35 percent (Collins 2008). A postbubble analysis observed that the most problematic grain during the 2007–2008 food price crisis was rice, which is not linked to biofuels in any way (Timmer 2010).

The corollary question for those interested in land policy is, what happened to land prices during the recent biofuels bubble? Impacts should be most visible in Iowa, the U.S. state at the epicenter of the corn ethanol boom. Figure 5.2 shows the pattern of annual percentage changes in inflation-adjusted agricultural land prices in Iowa since 1951. There was a one-year jump in land prices in 2007 that, based on its timing, could be attributed to U.S. ethanol policy making. However, it was not unusually large in historical terms, and it did not persist. When asked to identify factors pushing up land prices, farmers most frequently identified low interest rates (45 percent), high commodity prices (30 percent), high yields (24 percent), and a limited supply of land available for sale (20 percent) (Duffy 2009). Thus, the biofuels boom was just one of many factors

Figure 5.2
Annual Percentage Change in Inflation-Adjusted Iowa Agricultural Land Values



Source: Duffy (2009).

affecting Iowa's agricultural land market, and it was hidden within the commodity food crop price category. These unexciting short-term results do not rule out more significant impacts on land prices in the longer run.

Nonetheless, researchers are considering ways to resolve the competition between bioenergy crops and food crops without accelerating deforestation. Field, Campbell, and Lobell (2007) estimate that 5 percent of current global energy demand could be met by using abandoned agricultural land for cultivating biofuels. Campbell et al. (2008) put that number at 8 percent.

Innovation may allow bioenergy to become more attractive and less land intensive. Edgerton (2009) reveals the potential for productivity improvements in cross-national comparisons that show production averaging 7.5 tonnes per hectare in high-yielding countries versus only 2.8 tonnes per hectare in low-yielding countries. Tilman, Hill, and Lehman (2006) propose low-input, high-diversity grasslands instead of monocultures. Tilman et al. (2009) identify double- and mixed-cropping systems that deliver both biofuels and food. Campbell, Lobell, and Field (2009) calculate that it is more efficient and less land intensive to use bioelectricity than ethanol in transportation.

Even though bioenergy cannot scale up to serve a majority of the world's energy needs, it can play a role in the energy economy, especially as a substitute for petroleum fuels used in transportation. Important land policy issues associated with bioenergy include the need to avoid both deforestation and competition with food crops, to manage unintended side effects such as increased nitrogen cycling, and to promote productivity-enhancing innovations.

Land intensity is only one basis for comparing land use implications of different renewable energy sources. Others include land development costs, negative impacts on property values and the environment, and the time cost of public consultation. In addition, the availability of other constrained resources such as water may limit the deployment of renewables. For example, the cooling-water requirements of solar thermal power plants could force developers to rely on more expensive dry-cooling tower technologies in desert regions (Moore 2010).

What Is the Impact of Renewables on Electricity Transmission Networks?

Electric power systems have grown over the past 130 years from isolated laboratory experiments to mature, interconnected systems on a continental scale. The power grid was chosen as "the greatest engineering achievement of the 20th Century" (NAE 2000), in acknowledgment of its ability to improve people's lives by transforming diverse sources of primary energy into a clean, controllable energy carrier capable of being transmitted over long distances. The components of electric power systems—generators, transmission and distribution networks, and end-use equipment—are seamlessly interconnected even though they may be owned by different parties. Increasingly sophisticated information systems, business practices, and regulatory frameworks allow electric power systems to operate in a reliable and cost-effective manner. Building transmission systems that deliver high-voltage power from generators to distribution networks involves technically complex planning studies, politically challenging siting processes, and economically significant levels of investment. These systems are a critical part of the alternative energy story because they connect remote sources of energy to end users. Transmission lines themselves are not particularly land intensive (about five hectares per transmission kilometer, or twenty acres per transmission mile) or expensive (about US$2.5 million per transmission kilometer, or US$4 million per transmission mile), but they are enablers of the land-intensive renewable energy economy.[2]

Grand visions for transforming electric power networks to accommodate renewables have emerged all around the world. Figures 5.3 and 5.4 show proposals

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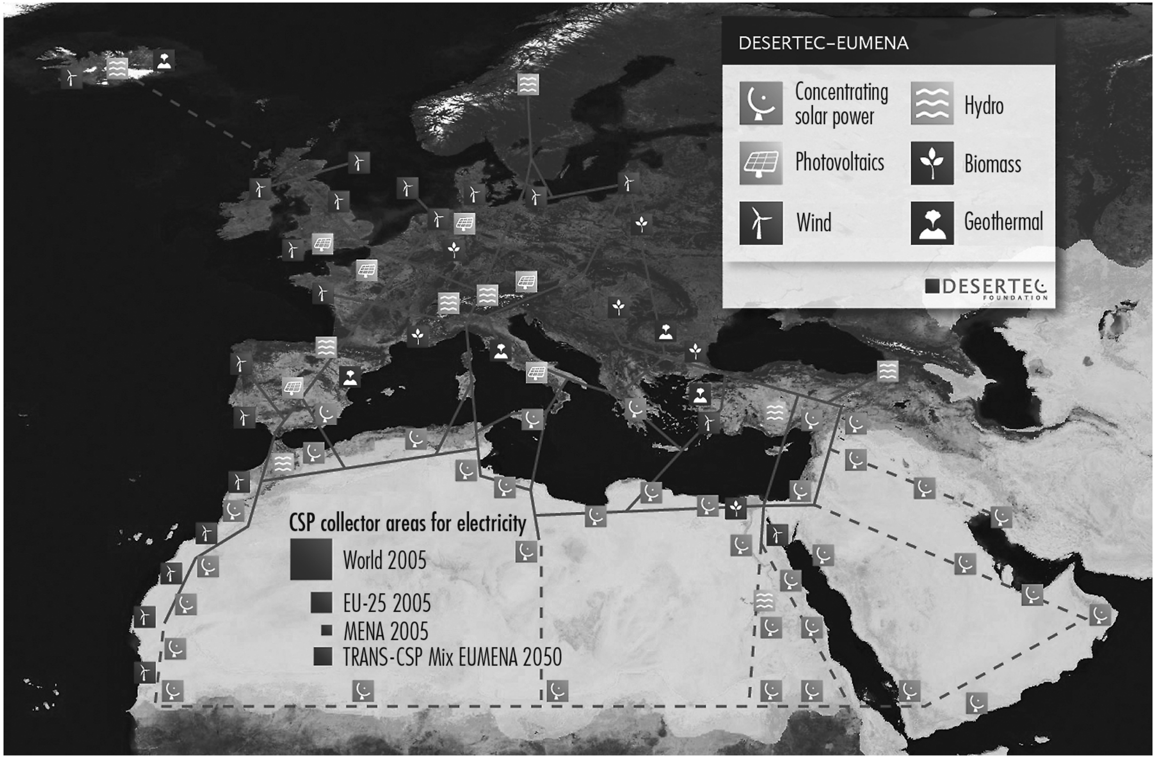
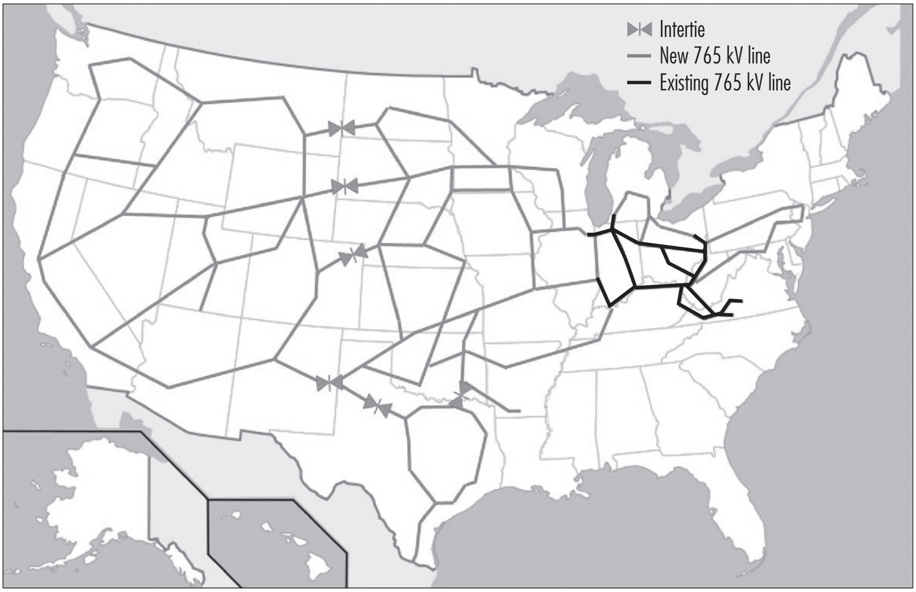
[2] These estimates are based on an average across 14 transmission planning studies: AEP (2007); MidwestISO (2009); Mills, Phadke, and Wiser (2010); NERC (2009b); NREL (2010a); USDOE (2008); and Wood and Church (2009).

Figure 5.3
Desertec Proposal for Installing Solar Thermal Energy Systems in the Sahara and Arabian Deserts



Source: Desertec Foundation (2010), www.desertec.org.

Figure 5.4
Proposed U.S. High-Voltage Transmission System for Wind Power Integration



Source: Messerly (2008), based on AEP (2007).

from either side of the Atlantic Ocean. Figure 5.3 illustrates the Desertec concept, which involves installing large solar thermal energy systems in the Sahara and Arabian deserts and delivering that energy to Europe via approximately 20 high-voltage direct current (HVDC) transmission lines. Figure 5.4 shows a more incrementalist vision to connect wind resources in the U.S. heartland with load centers on the coasts, using dozens of additions to the existing AC network.

INDUSTRY AND REGULATORY CONTEXT

To understand better how renewables are affecting transmission networks, it is useful to examine the near-term actions that the industry and its regulators are taking. In many countries, the electric power sector has undergone restructuring that affects both the incentives to invest in transmission capacity and the ability to optimize network performance. Following more than a decade of electricity sector reforms, policy makers are striving to balance cost-effectiveness, reliability, and levels of competition (IEA 2005). Whether the primary reason is to improve efficiency (western Europe and the United States) or to attract private investment (China and India), restructuring typically involves the unbundling of transmission and generation, thereby adding operational and investment challenges (Wu, Zheng, and Wen 2006). In general, jurisdictions with liberalized electricity markets are seeing declines in the rate of investment in transmission systems (IEA 2005).

INTEGRATING INTERMITTENT RENEWABLES

Wind and solar resources impose special demands on electric power systems. In North America, the organization responsible for assessing the reliability of the bulk power system is the North American Electric Reliability Corporation (NERC). NERC (2009b) notes that an additional 260,000 megawatts (MW) of renewable capacity is projected over the next 10 years in the NERC region, with 229,000 MW coming from wind energy. In the United States, increased renewable energy generation is driven primarily by federal tax credits and state renewable portfolio standards (RPS). Wind is abundantly available in many onshore and offshore areas, most notably in the Midwest (Manjure and Osborne 2008). Therefore, a large percentage of the queues for interconnecting proposed generators are for wind generators.

In 2004 distributed and renewable generation accounted for nearly 45 percent of the total electricity production in Denmark and 20 percent in Germany, Spain, and Sweden (Cossent, Gomez, and Frias 2009). By 2018 NERC (2009b) expects wind to account for 18 percent of the total North American resource mix. However, wind energy often arrives off-peak, so it will satisfy only about 3 percent of peak demand.

Wind has a low capacity factor (30–40 percent annually), which diminishes the economic attractiveness of dedicated transmission lines (Mills, Wiser, and Porter 2009). Additionally, wind resources are often located away from demand centers, commonly in areas without existing transmission lines. The natural variability issues, along with the location-specific nature of renewable energy sources and renewable capacity legislation, present operational and planning challenges (NERC 2009b). The growth in renewables and the growth in transmission needs are highly correlated, with the Midwest, Texas, and California being the U.S. hot spots (NERC 2009b).

NERC (2009b) projects that 51,500 km (32,000 miles) of transmission lines will be constructed between 2009 and 2018, of which 35 percent must be constructed on time to avoid severe reliability problems. However, many obstacles, most notably transmission line siting, hamper construction timelines.

Interconnection queues have seen a sharp increase in the volume of wind generator requests (both number of requests and megawatts requested). The limitations of the transmission capacity have created a backlog of requests that are waiting on interconnection studies (Manjure and Osborne 2008). Subsequently, MidwestISO initiated several studies, and the National Renewable Energy Laboratory, on behalf of the U.S. Department of Energy, has begun two large-scale, ongoing wind integration studies—the Eastern Wind Integration and Transmission Study and the Western Wind and Solar Integration Study. Similar studies are being performed in Europe and China. A surprising early finding of the Western Wind and Solar Integration Study is that the majority of transmission line expansions will be relatively short, just 230–315 miles (370–507 km) (Mills, Phadke, and Wiser 2010).

COMPARISON OF TRANSMISSION FOR LAND-BASED WIND AND OFFSHORE WIND

Crowded onshore landscapes and good offshore wind resources have encouraged European and North American planners to pursue offshore sites. Europe has far more experience with such sites.

Offshore wind requires submarine cables to carry power from the offshore turbines or substations to onshore substations for connection to transmission lines and load centers. As the United States aims to increase offshore wind projects, developers are looking to Europe to gain insight into the lessons learned from their experiences. The United States lacks domestic manufacturers and installers of high-capacity submarine cables, and even the Europeans have found such installations to be difficult and costly (Wright et al. 2002). High-voltage alternating current (HVAC) cables are able to connect flexibly to existing AC grids, but they encounter technical challenges in offshore applications (NERC 2009a). The high-voltage cables required by wind transmission have highly reactive current demands as a result of their induction generators. This is problematic because it causes resonance with the capacitance of the cables (Wright et al. 2002). Recent advances in voltage source converter (VSC) technologies and HVDC transmission may be the answer for future offshore transmission (NERC 2009a).

The precise costs of transmission infrastructure for offshore wind are relatively unknown because the parts must be custom manufactured (Green et al. 2007). However, transmission costs were a small fraction of the overall costs in all four scenarios in the Eastern Wind Integration and Transmission Study, including those with aggressive offshore targets (NREL 2010a).

Transmission issues in the United States may be magnified by the relative size of the planned offshore projects, which are more ambitious than the first European wind farms (Snyder and Kaiser 2009). The relative inexperience of U.S. developers and the size of the projects, coupled with the added difficulties of conducting the energy to the load centers onshore, could slow these projects' completion.

Van Hulle (2009) promotes an interlinked or meshed offshore grid linking offshore wind farms in the North and Baltic seas with the onshore transmission grid in order to increase cable utilization, enhance grid stability, and improve power-trading opportunities in Europe. Although the U.S. offshore wind industry is far from considering such a system (no offshore facilities are in operation yet in the United States), future wind studies may well consider interlinking offshore facilities, especially on the densely populated eastern seaboard, if offshore wind development expands significantly.

Offshore wind relies on onshore transmission systems (van Hulle 2009). Therefore, the discussions of onshore transmission upgrades, costs, and challenges also apply to offshore wind projects.

DISTRIBUTED GENERATION

On the opposite end of the spectrum from the transmission superhighways promoted by some studies (e.g., AEP 2007; USDOE 2008), distributed generation (DG) integrates renewables into the grid through small-scale generation that is connected on the customer's side of the meter or on the local distribution network (Ackermann, Andersson, and Soder 2001). Recent literature indicates a shift from the superhighway approach to an increased focus on DG as part of the solution.

Lovins (1977) discussed the benefits of generating energy at or near the demand site in his classic book *Soft Energy Paths*. He advocated for the use of renewable energy sources and energy generation that appropriately matched specific demand. Although current DG builds on this concept, DG systems today are connected to the grid, and interconnection is a key element of projects and proposals. DG is not the ideological concept that Lovins imagined. Instead, it has expanded, and the energy conservation that Lovins stressed is no longer a driving force for DG penetration into the market. Increasing reliability and resilience in the face of grid disturbances now take precedence. For example, one utility is installing small solar units on 200,000 utility poles in New Jersey (PSE&G 2010). This solar power flows into the electric grid. Generation is not matched specifically to demand, as is the case with a rooftop panel that provides energy to the building on which it sits. PSE&G's pole-attached panels combine Lovins's "soft path" approach and the more traditional "hard path" approach to matching generation and demand.

In sum, the transmission capacity that is needed for renewables to make a significant contribution to the global energy balance is not easily built. The industrial structure and regulatory compacts in many countries do little to encourage the construction of new lines. In addition, there are technical challenges associated with the intermittency of renewables and the cost of underwater cables. Finally, there are siting difficulties and public skepticism about the need for new transmission lines.

What Is the State of Siting Policy Today?

One way to determine the outcomes of renewable energy permitting processes is simply to compare the levels of renewable energy supplies that have successfully received required permits in each nation. Europe has had much more success in permitting than any other part of the world. At the end of 2009, Europe had a total of 76,263 MW of installed wind turbines, almost double that in North America or Asia, although new capacity is being built more rapidly in Asia than elsewhere (WWEA 2010). Globally, wind generation capacity is 159,213 MW, producing 340 TWh-yr, or about 2 percent of worldwide electricity consumption (WWEA 2010).

National permitting regulations play a significant part in the ability of nations to deploy renewable energy generation. Many European elected officials and parliaments profess a desire to increase their renewable portfolios, but only a few have actually lived up to those aspirations. Germany and Spain, in particular, have made significant strides in building wind generation facilities, and each has permissive laws that make it easier for wind developers to receive permits for their projects. In contrast, although The Netherlands has aggressive goals for renewables, it has not achieved them, largely because of political conflicts at the local level that have beset the permitting process.

PUBLIC PERCEPTIONS

Public opposition to transmission lines is frequently associated with the infamous acronym NIMBY (not in my backyard). In this regard, opponents are concerned about property values, aesthetics, health and safety, compensation levels, and the demonstrated need for new lines (IEA 2007; Vajjhala and Fischbeck 2006). But this characterization obscures a wide variety of public and stakeholder opinions, as well as a process that is inevitably becoming more iterative and less linear, more tactical and less coherent (Vajjhala and Fischbeck 2006).

Transmission lines are increasingly being built to move renewable energy to market, thereby splitting the environmental coalitions that have fought previous lines. Where NIMBY opposition conflicts with national policy goals such as reducing carbon emissions, local opponents can expect less outside help in the future (Wasserstrom and Reider 2010).

Vajjhala and Fischbeck quantified U.S. siting challenges in terms of economic, geographic, construction, and perception factors, and they found that "states with the greatest incentives to develop renewable energy also face the most serious obstacles to siting new facilities" (2006, 1). Subsequent regression analysis of the relative importance of public opposition, government regulation, and landscape characteristics indicates that public opposition is by far the most important challenge.

These findings beg the question of whether there is a technical fix that might reduce public opposition, such as burying transmission lines instead of stringing them overhead. The industry has resisted widespread use of the burial option because of its cost and performance constraints, but that is beginning to change. Discussion of the technical trade-offs is now more nuanced: overhead lines are more vulnerable to weather-related disruptions but take less time to repair than underground lines; underground lines must be limited in length to less than 50 km (31 miles) due to ground-based installation logistics (Prysmian Powerlink 2009). Recent assessments place the cost differential in the range of four to ten times the cost of an equivalent overhead line (Brown and Sedano 2004; Hall, Kennedy, and Hager 2007; USDOE 2006), compared to a factor of twenty a generation ago (Howard 1973). Transmission represents a small fraction of the total cost of electricity—4–6 percent in the United States (EIA 2010a, table 8.1; ISO New England 2006)—although it accounts for a much higher fraction of investment costs. Unregulated "merchant" power plant developers are more willing to trade the higher investment costs of underground transmission lines for expedited siting approvals than are regulated utilities that must make “least cost” decisions (Wood 2009). As a result, underground lines are still the exception rather than the rule.

ENERGY FACILITY SITING POLICIES

Each energy source comes with potential siting conflicts. Former vice president Al Gore famously won the right to install solar panels on his Tennessee home, but not without a fight waged with his town government (Munoz 2007). The clash over the siting of wind turbines has been called “the mother of all NIMBY wars” (Durlijn 2009), a sobriquet once reserved for nuclear power plants.

In nearly all countries, with the notable exception of Spain (Toke, Breukers, and Wolsink 2008), siting is a matter of local government approval (Wolsink 2007). The framework for implementation, however, is nearly always set by the federal government. In the United States, the federal government works in cooperation with the states. The siting policy set by the Telecommunications Act of 1996 (47 U.S.C. Sec. 332 [2006]) offers one possible model of intergovernmental cooperation for siting future energy facilities (Salkin and Ostrow 2009).

Full local control over large-scale energy projects is problematic because it often fails to consider regional needs (Rosenberg 2008). The following U.S. states have locally based processes that do not involve state review or assistance: Colorado, Idaho, Illinois, Iowa, Kansas, Nevada, North Carolina, Oregon, Texas, and Utah. The U.S. states that have enacted special state-level processes include Arizona, California, Connecticut, Florida, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Jersey, New Mexico, North Dakota, Ohio, Oklahoma, Oregon, Vermont, Virginia, Washington, and Wisconsin (EEI 2004).

Whether the processes are effective at simplifying the permitting process is a separate question. Wind power currently accounts for just over 1 percent of U.S. electricity production. The states with the greatest installed capacity are Texas and California, with 4,356 MW and 2,438 MW, respectively. The remainder of the top ten are Minnesota (1,299), Iowa (1,273), Washington (1,123), Colorado (1,066), Oregon (885), Illinois (699), Oklahoma (689), and New Mexico (495) (AWEA 2008).

Many countries are having difficulty meeting national renewable energy targets, although Germany, Denmark, and Spain have implemented a significant amount of renewable energy. In all Western countries, with the possible exception of Spain, local governments have considerable ability to influence the outcome of energy development projects. Germany and Denmark take a middle-ground, proactive planning–type approach, where local governments must proactively guide the development of renewable energy sources. Regardless of the particulars, proactive voices in local communities influence representatives in national parliaments, often preventing a reorganizing of power structures. Toke, Breukers, and Wolsink (2008) advocate a collaborative approach to decision making that empowers and involves interested parties and local governments from the outset.

Such efforts can benefit from active mediation (Susskind and Field 1996). In the case of large-scale, land-intensive, and impact-laden projects such as wind farms, a zoning-type approach also may be appropriate.

In Europe, one of the significant challenges in expanding renewable energy has been opposition from "landscape protection groups," which have as their vested interest protection of the cultural and scenic landscape. Toke, Breukers, and Wolsink (2008) say that overall outcomes in Europe are largely linked to the strength of these groups, which are weakest in Spain and strongest in England, Wales, and Scotland.

Empirical research suggests that the opposition to new wind farms follows a U-shaped curve. When no project is proposed for a particular area, opinions about wind farms are generally positive. When a wind project is announced, opinions become more negative, but as time passes they become more positive again (Devine-Wright 2005; Gipe 1995; Pasqualetti 2002). This suggests that although there are few long-term impacts, fear of such impacts can be significant and politically potent (Toke, Breukers, and Wolsink 2008).

TRANSMISSION SITING POLICIES

According to NERC (2009b, 26), "The ability to site and build transmission is emerging as one of the highest risks facing the electric industry over the next ten years." Although the distance and extent of transmission needs vary, transmission upgrades and new projects will be vital to meet growing energy demands and renewable energy targets. However, numerous challenges to transmission siting exist.

In the United States and elsewhere, regulatory oversight of transmission projects falls in vertically and horizontally fragmented fashion under both federal and state authorities. EEI (2004) data indicate that each state's permitting process is unique: some states have no state oversight (with a few situational exceptions); some have a single permitting agency, with caveats based on scale of project impact; and others have multiple permitting agencies. Often, the sequence of the involvement of various agencies is inappropriate. For example, in many cases federal involvement occurs only after the state and local permitting processes have already begun (Vajjhala and Fischbeck 2006).

Additionally, transmission projects can span multiple states or regions, almost always involve multiple landowners and constituencies, and typically involve publicly visible lines that are regulated by multiple agencies (Wood and Church 2009). While experts call for streamlined regulatory policies, "state regulators remain adamantly opposed" on classic federalist grounds (Wasserstrom and Reider 2010, 13).

The current regulatory framework creates other mismatches in addition to siting problems. State policy makers dictate RPS or similar measures, often without regard to implementation intricacies such as transmission. A further complication is that "generation and demand-side resource adequacy planning and assessment can be performed by multiple independent entities" (NERC 2009a, 34). This is problematic because transmission planning and resource adequacy assessment are interrelated, as generation must meet demand (NERC 2009a).

In February 2009, President Barack Obama vowed to "lay down thousands of miles of new power lines that can carry new energy to cities and towns across the country" (Obama 2009, 6). In spite of the clear need to upgrade the robustness and redundancy of the transmission system since the catastrophic blackout in the northeastern United States in 2003, as well as the push to expand renewable energy production, the intergovernmental challenges persist. This remains true in most countries around the world.

Conclusions

The land requirements of a renewable energy economy are daunting, more so politically than economically. Solar thermal and geothermal have the smallest land footprints, but are available only in certain locations; wind has a larger footprint and similar limited suitable locations, which include offshore possibilities; solar photovoltaics have a large footprint, but fewer locational constraints; and bioenergy has by far the largest land requirements per unit of energy delivered. Although each of these resources, except bioenergy, could probably satisfy the entire global demand for energy, it is more likely that a mix of resources will be deployed. Regional resources are leading analysts to envision different mixes in different jurisdictions, with the common elements including a demand-side emphasis on energy efficiency improvements and a supply-side emphasis on improved energy transmission capabilities (Divan and Kriekebaum 2009; MacKay 2009).

Most of the renewables are not yet cost competitive with conventional energy sources, so they require subsidies to encourage their deployment. Carbon taxation and functionally equivalent regulatory regimes such as RPS are starting to level the playing field. More important, technological development continues to reduce unit costs. Particularly important for the cost-efficient movement of electricity from intermittent wind and solar sites is the development of storage and control technologies that improve the capacity factor of the transmission lines.

The most significant noneconomic barrier to a successful transition to renewable energy is not the land requirements, but the siting challenges. The most cost-competitive renewable energy technology, wind power, continues to encounter public opposition, whether it is onshore or offshore. Although this opposition can be overcome by careful planning, respectful public processes, and a fair allocation of risks and rewards, all of these add time and costs to wind farm development.

Siting challenges are even greater for the transmission lines needed to move electric power from remote renewable energy generation sites to population centers. "Soft path," distributed renewable energy generation can help locally, but it will still be necessary to bolster transmission networks, especially to address transportation-related energy demands. Public policy makers could play a more decisive role in the siting of transmission lines by clarifying the need for, appropriate ownership of, and financing of each line and by coordinating regulatory reviews across what are inevitably multiple jurisdictions.

Local land use conflicts also need to be resolved through public policy making. Municipal governments need land use ordinances and plans to ensure solar and daylight access and to prevent interproperty spillovers from wellfields serving ground-source heat pump systems for heating and cooling buildings. Local planners need to understand the mix of renewable energy resources that make district energy systems and microgrids feasible, as well as the coordination required to make such systems work.

Finally, technological research must identify new ways of siting transmission lines. Burying lines dramatically reduces public opposition, but it remains a costly alternative to overhead lines. More research is needed to reduce this cost differential.

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