Bloomberg Green

# The U.S. Will Need a Lot of Land for a Zero-Carbon Economy

By Dave Merrill

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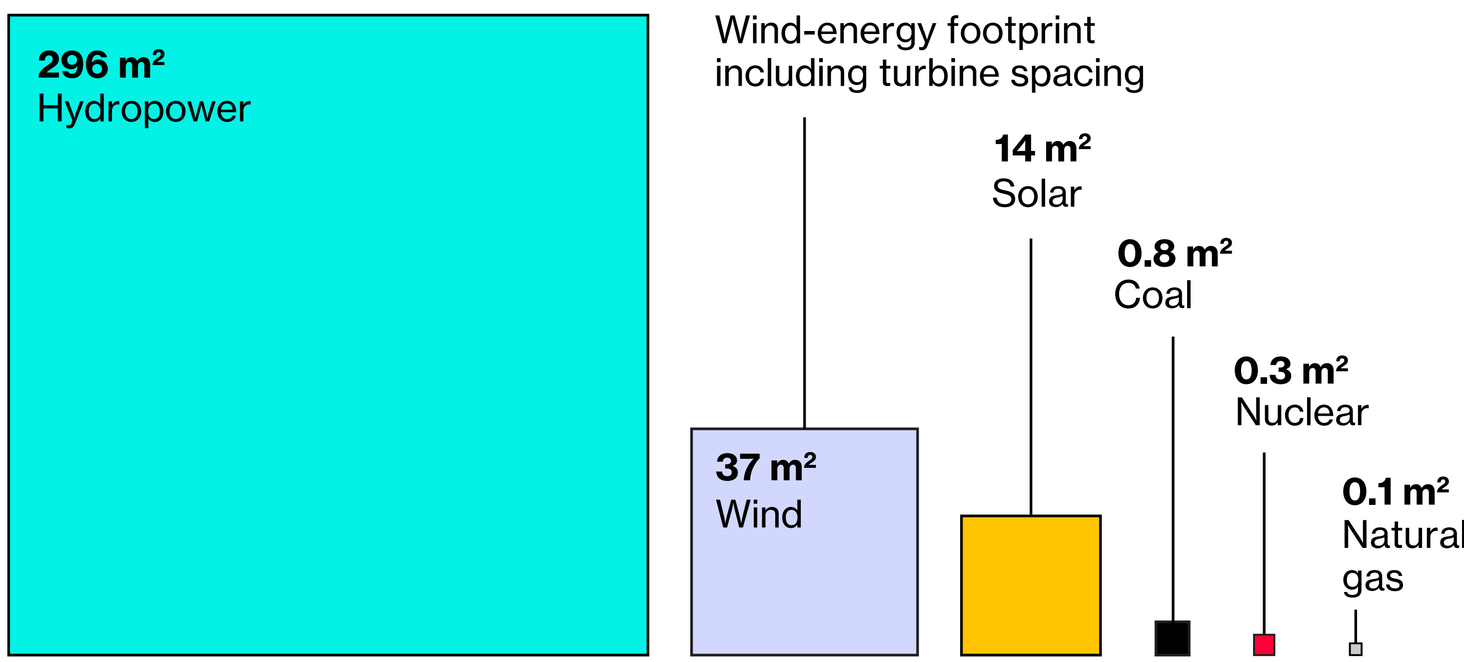
At his international climate summit last week, President Joe Biden vowed to cut U.S. greenhouse gas emissions in half by 2030. The goal will require sweeping changes in the power generation, transportation and manufacturing sectors. It will also require a tremendous amount of land.

Wind farms, solar installations and other forms of clean power take up far more space on a per-watt basis than their fossil-fuel-burning brethren. A 200-megawatt wind farm, for instance, might require spreading turbines over 19 square miles (49 square kilometres). A natural-gas power plant with that same generating capacity could fit onto a single city block.

Achieving Biden's goal will require aggressively building more wind and solar farms, in many cases combined with giant batteries. To fulfill his vision of an emission-free grid by 2035, the U.S. needs to increase its carbon-free capacity by at least 150%. Expanding wind and solar by 10% annually until 2030 would require a chunk of land equal to the state of South Dakota, according to Bloomberg and Princeton University estimates. By 2050, when Biden wants the entire economy to be carbon free, the U.S. will need up to four additional South Dakotas to develop enough clean power to run all the electric vehicles, factories and more.

**Power Densities: Renewables Need More Space**
Land area needed to power a flat-screen TV, by energy source

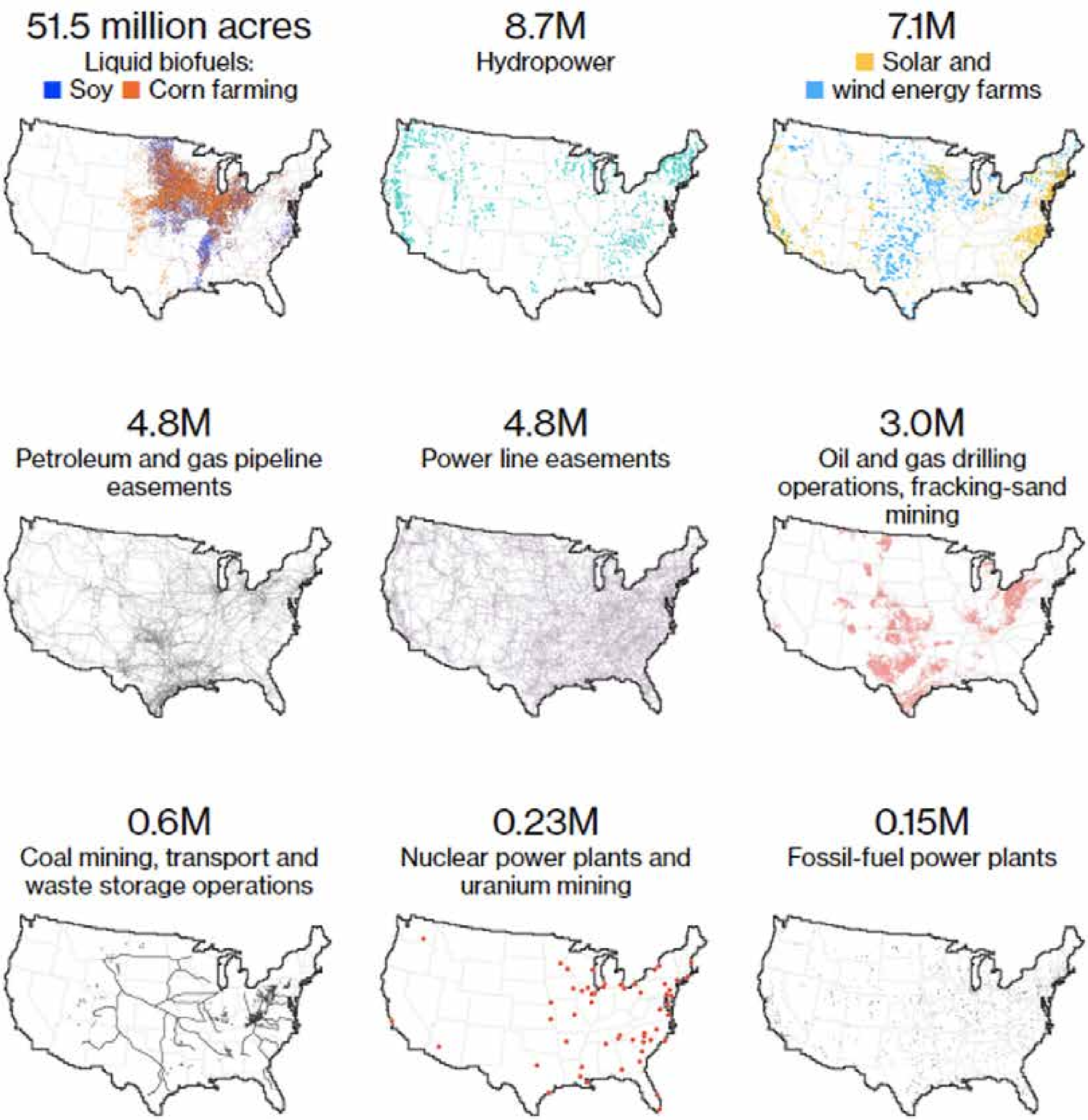



Note: Assumes 100-watt television operating year-round
Source: Leiden University, John van Zalk, Paul Behrens

To be clear, Biden's plan doesn't need to entirely rest on wind and solar. Nuclear energy, which requires far less space, is also emission free. Same for hydroelectric power. Plus, wind farms can be installed at sea. Solar panels work wonderfully on rooftops. And plenty of companies are placing bets that fossil-fuel plants can be retrofitted to burn hydrogen or equipped with systems to capture their carbon dioxide emissions.

Estimates vary widely on how much land the U.S. will need to satisfy Biden's clean-energy ambitions. A recent study by the U.K. think tank Carbon Tracker concluded that renewables actually require less space than fossil fuel. But no matter how you slice it, the U.S. will need to rethink land use for an emissions-free future. Here's how researchers at Princeton University's Net-Zero America project estimate it can be done.

## Today, the U.S. Uses 81 Million Acres to Power Its Economy

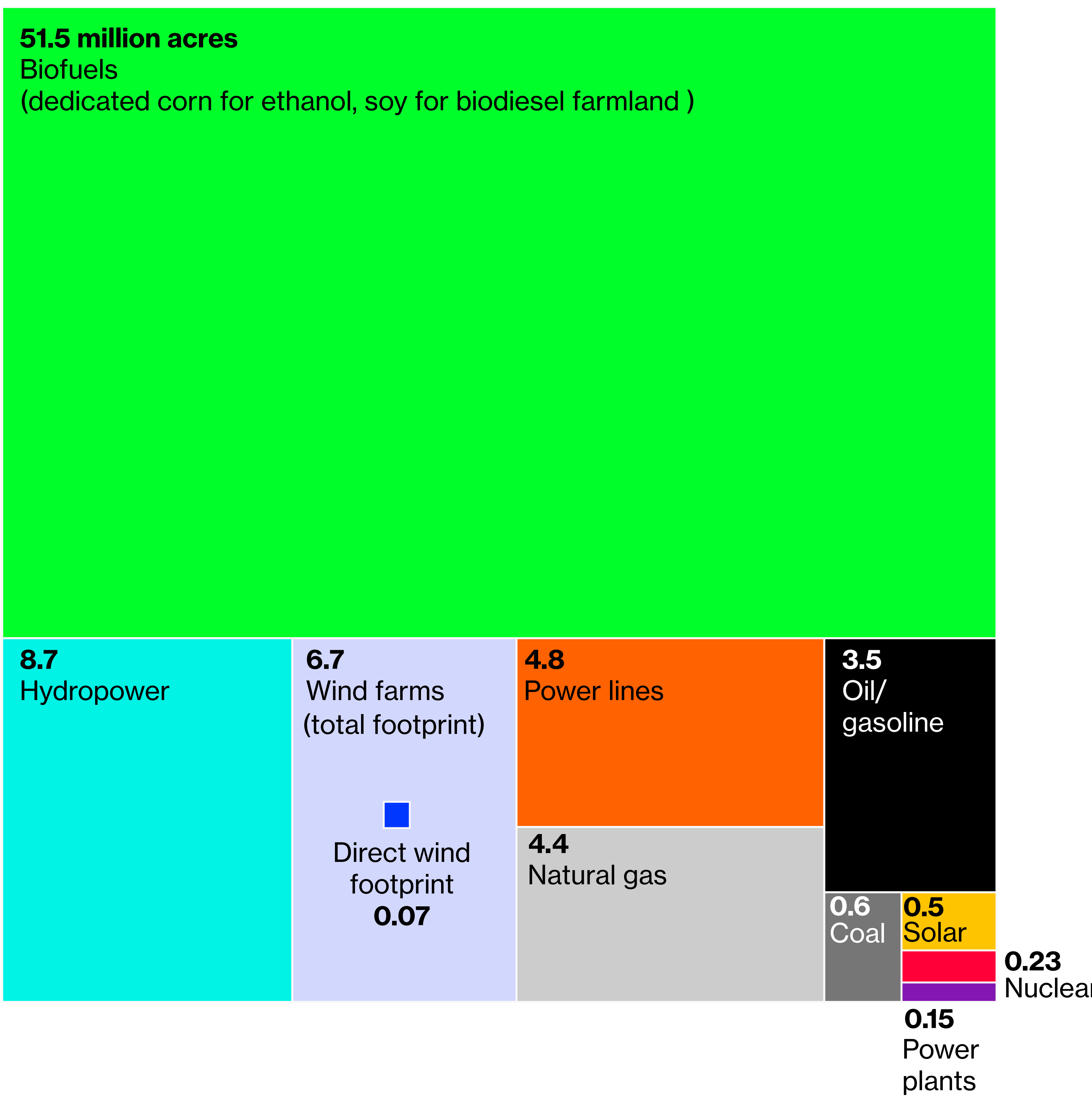



Note: Liquid biofuels map depicts soy and corn farming. One dot equals 10,000 crop acres. About one-third of the nation's corn and soy crops are used for biofuels.

Right now, the current U.S. energy sector requires about 81 million acres (33 million hectares) of land. That estimate includes not only energy sources fueling the electric grid, but also transportation, home-heating and manufacturing.

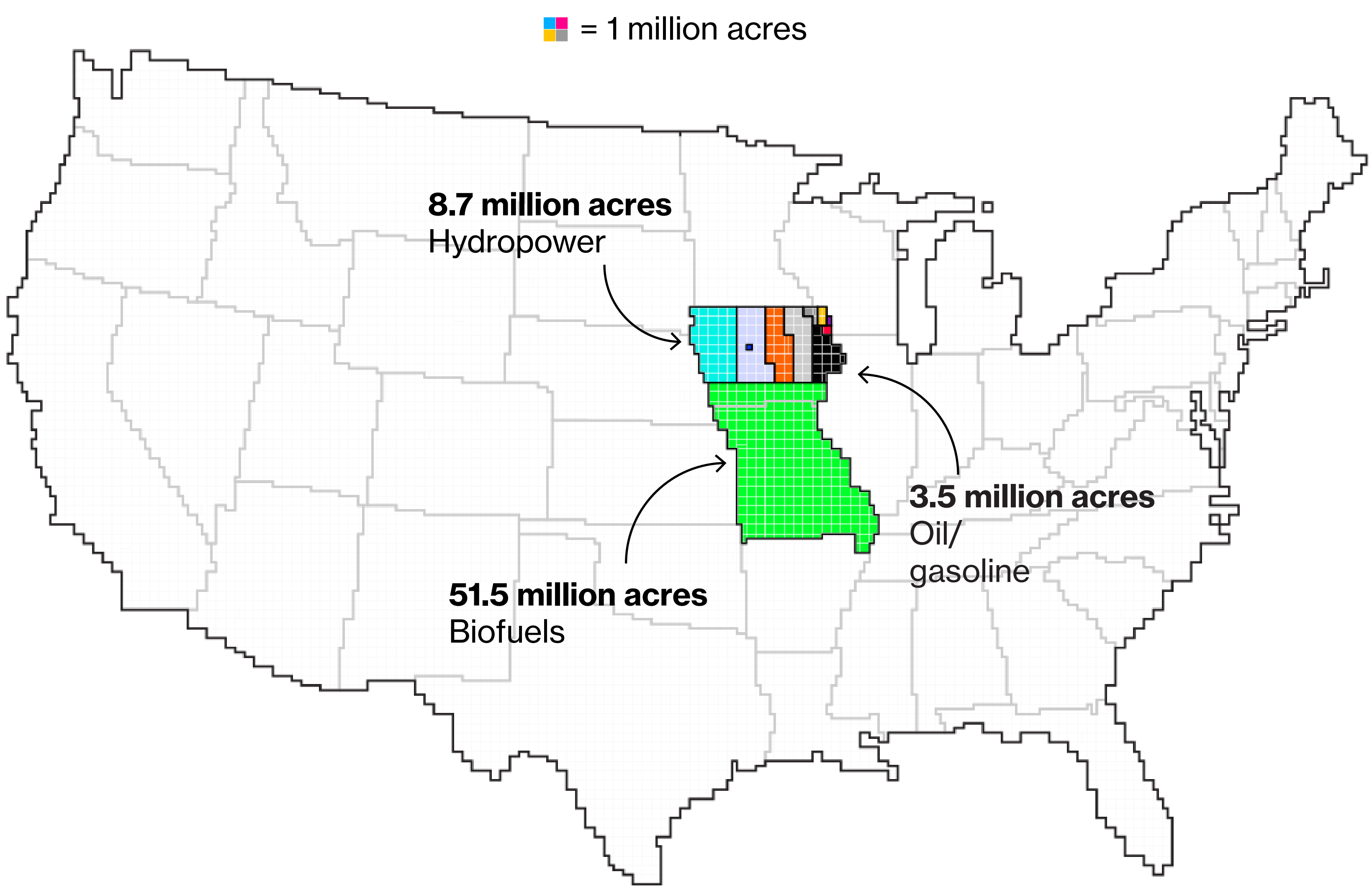
**Energy Land-Use Framework**

**81 Million Acres**



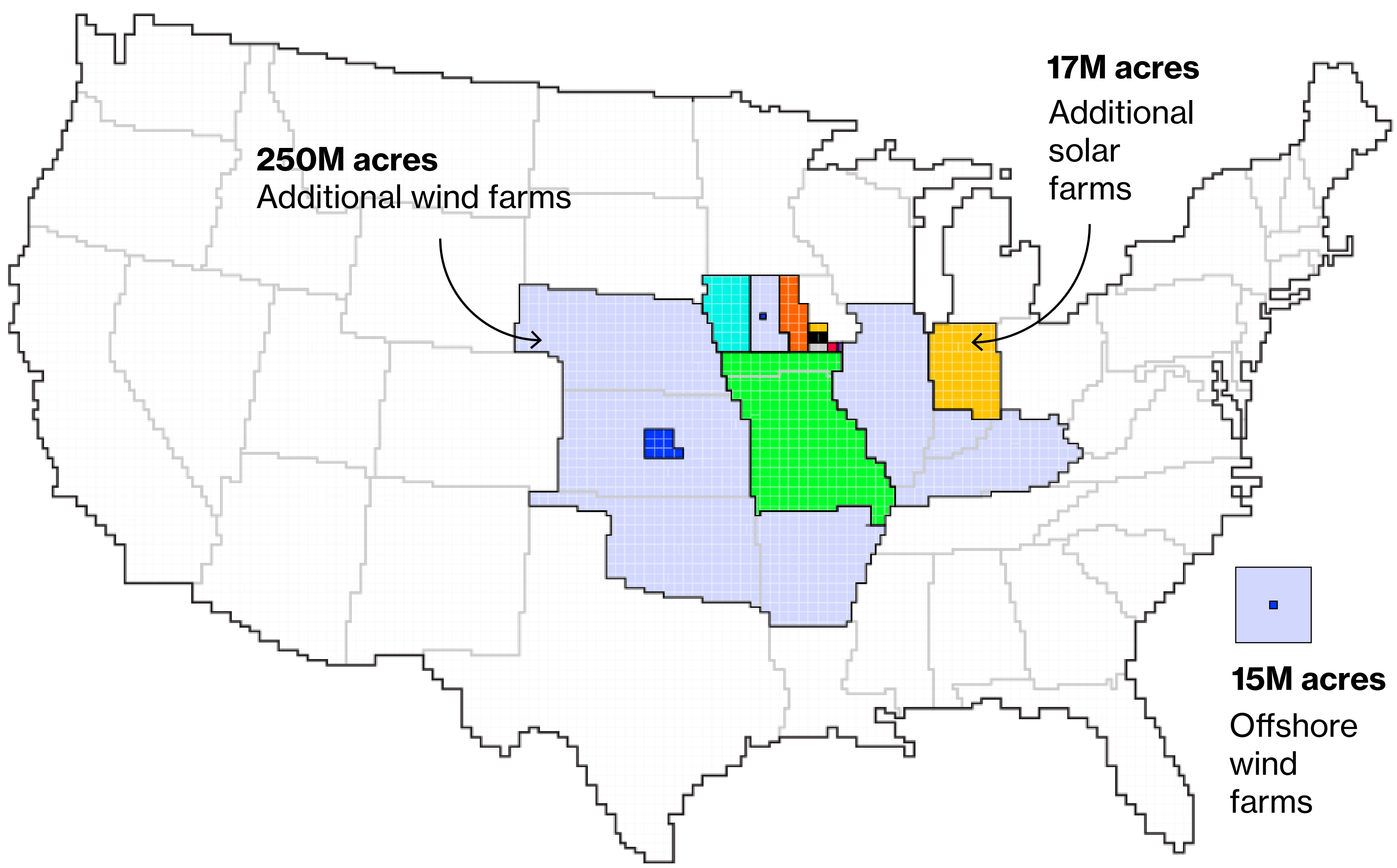

Note: Wind's direct footprint includes only turbine bases and access roads. See methodology below for complete accounting of land-use estimates

Two-thirds of America's total energy footprint is devoted to transportation fuels produced from agricultural crops, primarily corn grown for ethanol. It requires more land than all other power sources combined but provides just 5% of the nation's energy, making it the most land-intensive major fuel source.

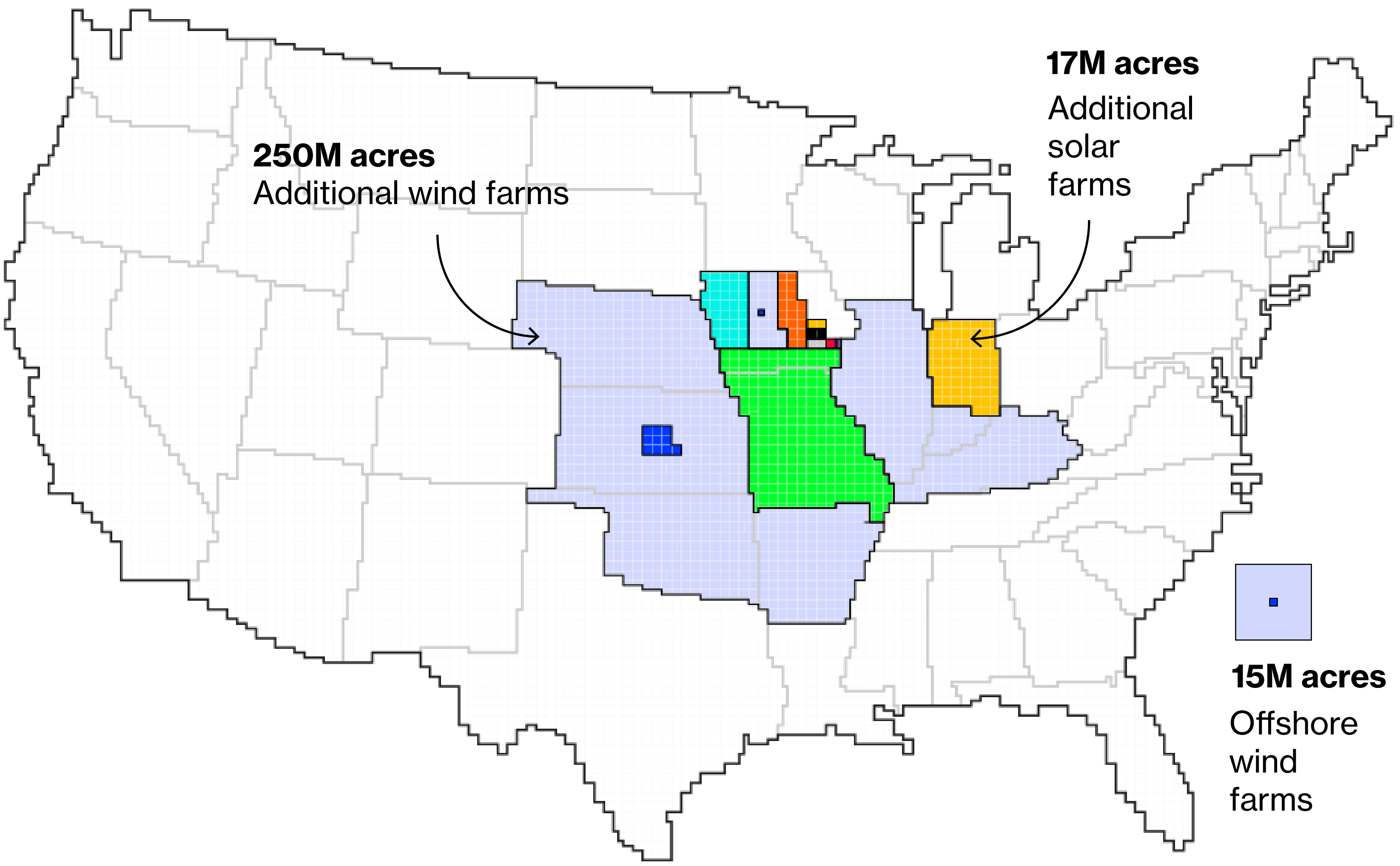



Here's how 81 million acres of energy acres lumped together looks on a U.S. map. Our current energy footprint is about the size of Iowa and Missouri combined, covering roughly 4% of the contiguous U.S. states.

Princeton University’s Net-Zero America Project maps various pathways to reaching a carbon-free U.S. by 2050. Each path has unique land-use challenges, from siting hundreds of new nuclear reactors to finding homes for one million wind turbines.

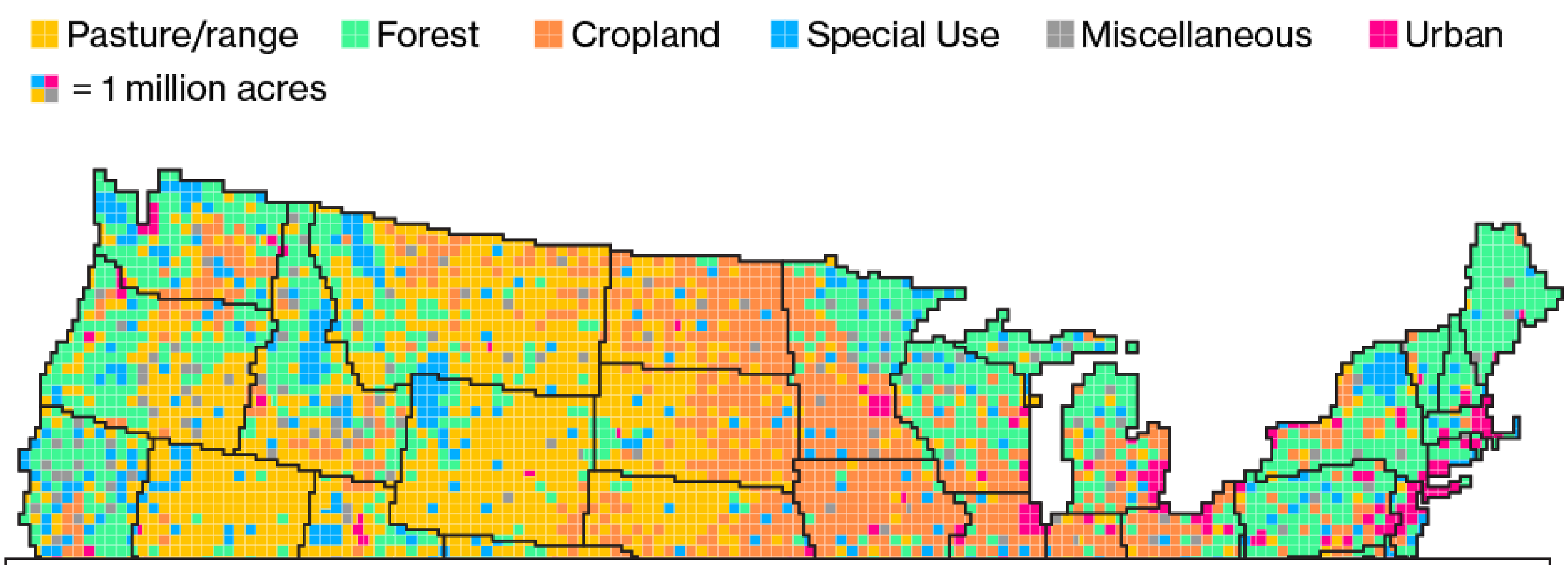



The most land-intensive plan eliminates all fossil fuels and nuclear plants. Wind and solar provide 98% of electric power by 2050. The U.S. energy footprint quadruples in size. Wind farms occupy land areas equivalent to Arkansas, Iowa, Kansas, Missouri, Nebraska and Oklahoma.

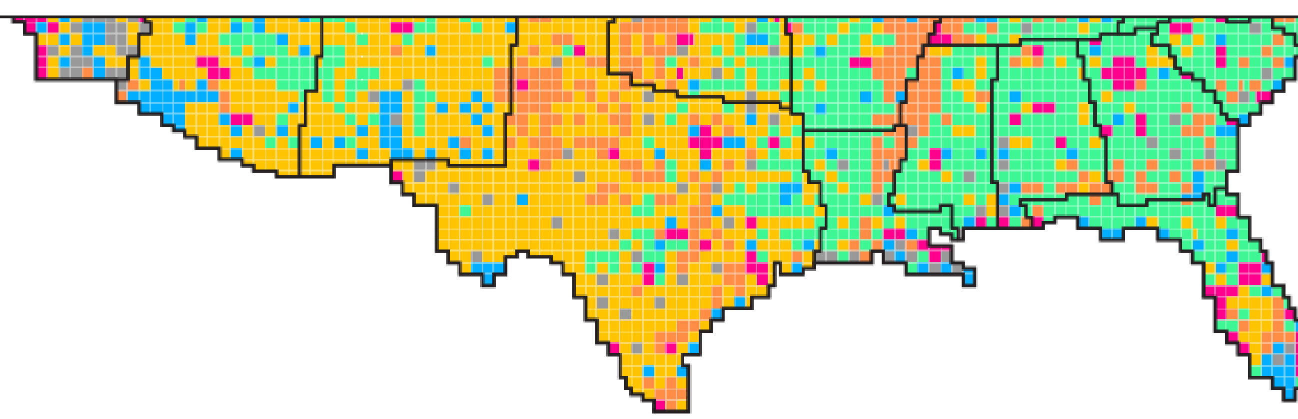


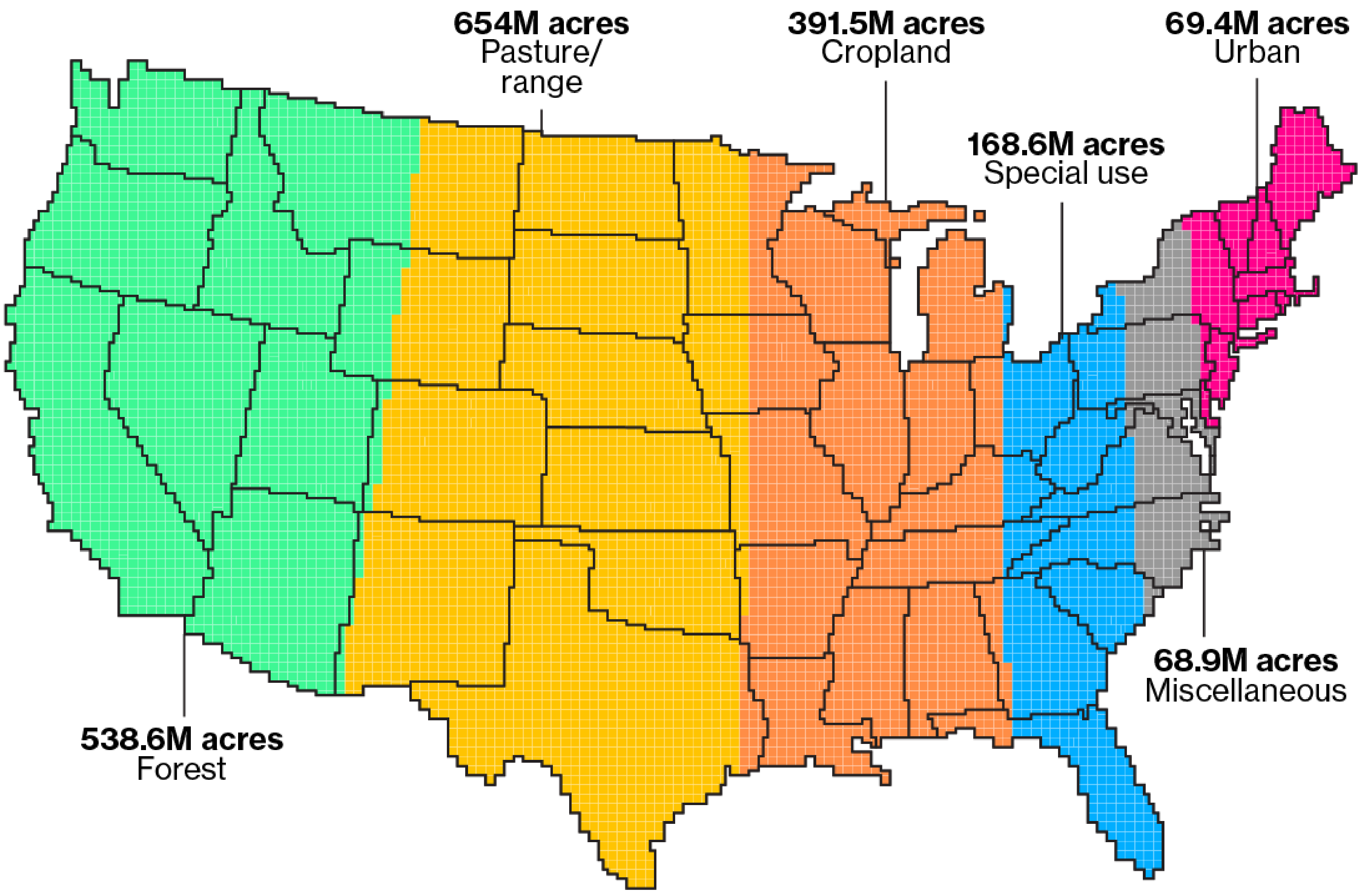

In this highly electrified economy, wind and solar provide four times the electric power capacity of the 2020 U.S. grid. Electricity powers all vehicles, heats homes and powers many industrial processes. When demand peaks and the grid needs an extra boost, it will come from a mix of batteries, hydropower and combustion turbines burning carbon-free synthetic fuels and hydrogen.

Is there even enough uninhabited land to build 250 million acres of new wind farms?

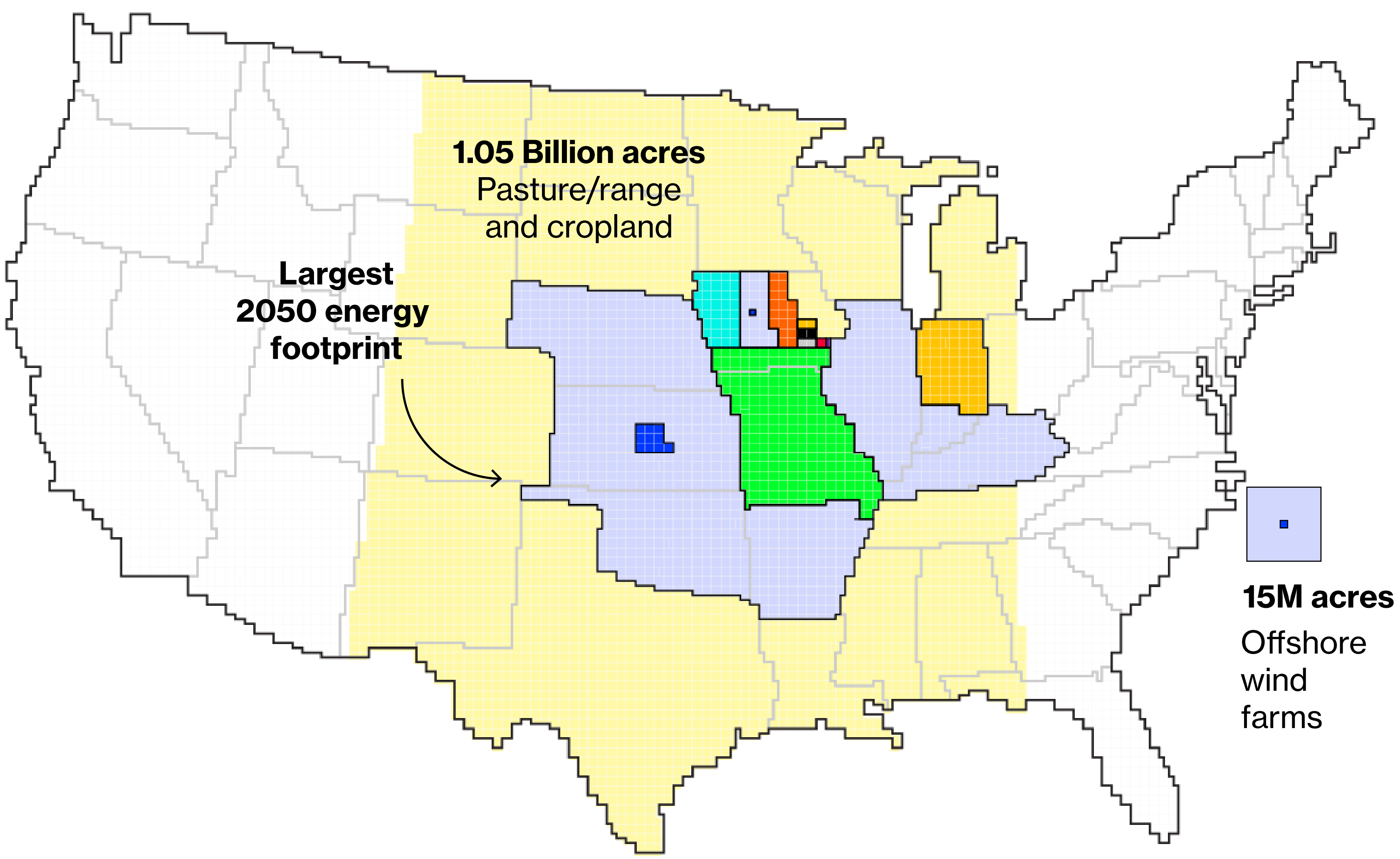



The short answer is yes, according to estimates from the U.S. Department of Agriculture.



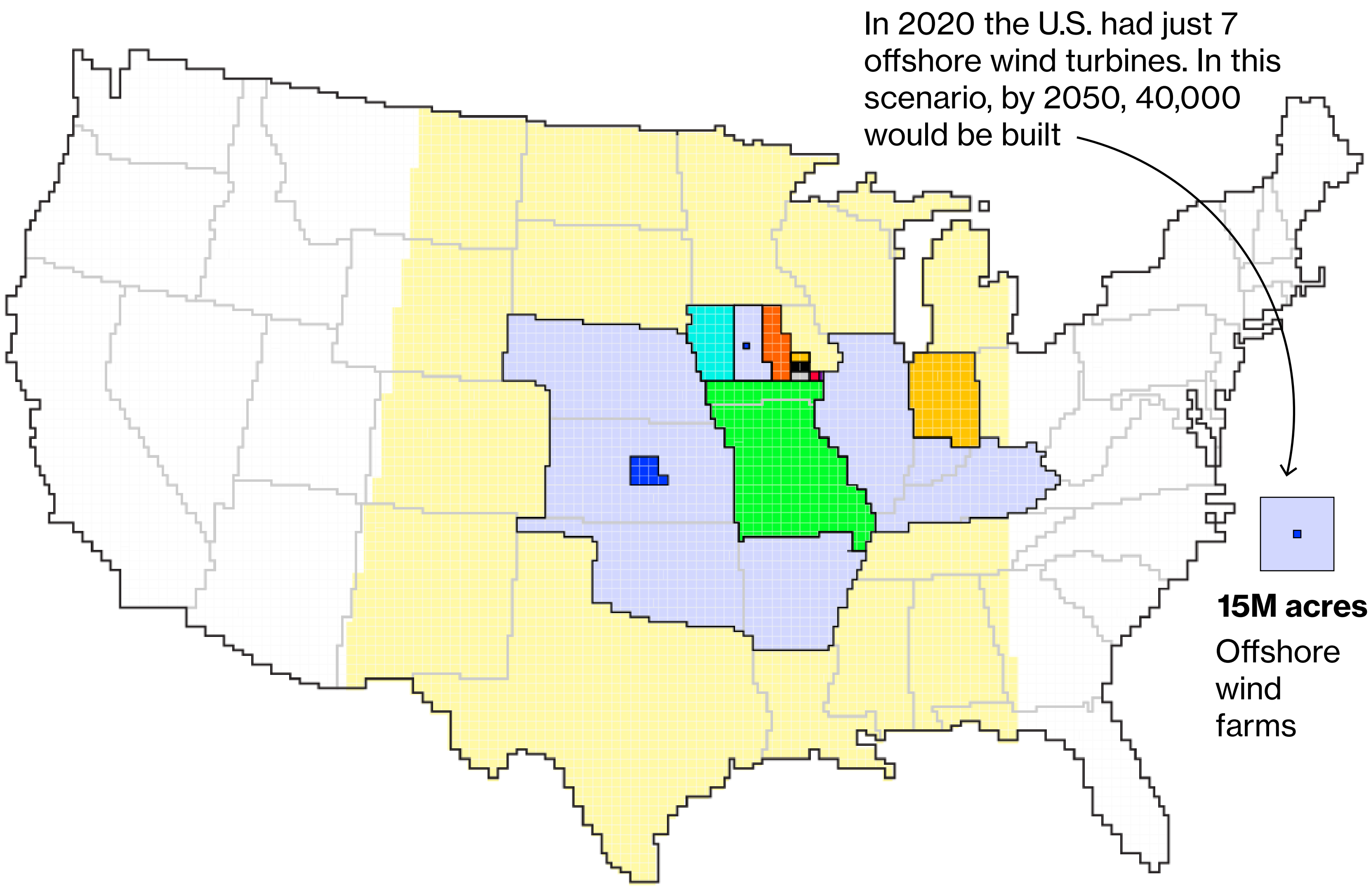



The contiguous U.S. is home to 654 million acres of pasture and 391 million acres of farmland. In many instances, wind turbines can be incorporated into those areas and have limited impact.

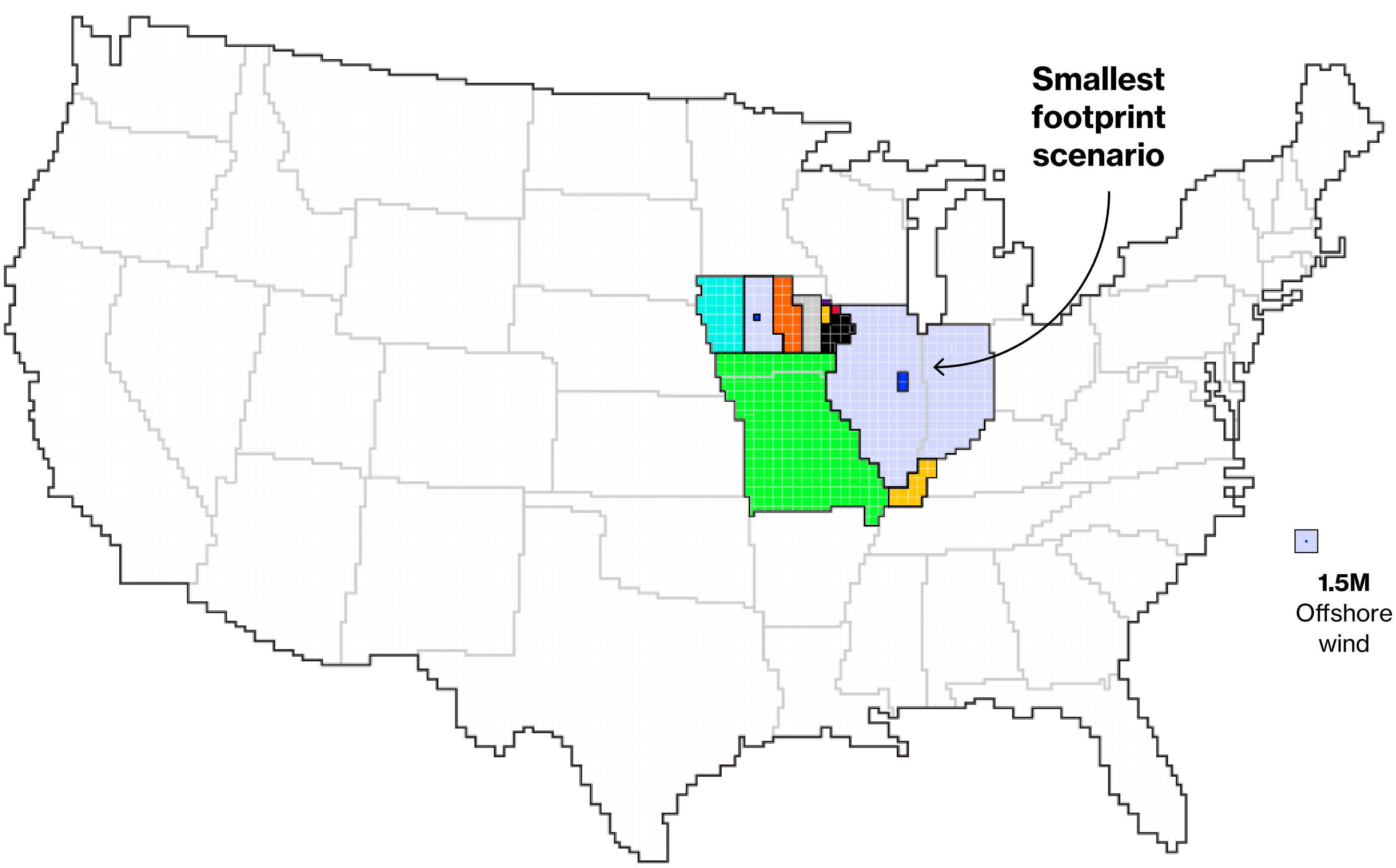



Plenty of U.S. ranch and farm owners already lease land for annual royalty payments, totaling $820 million last year.

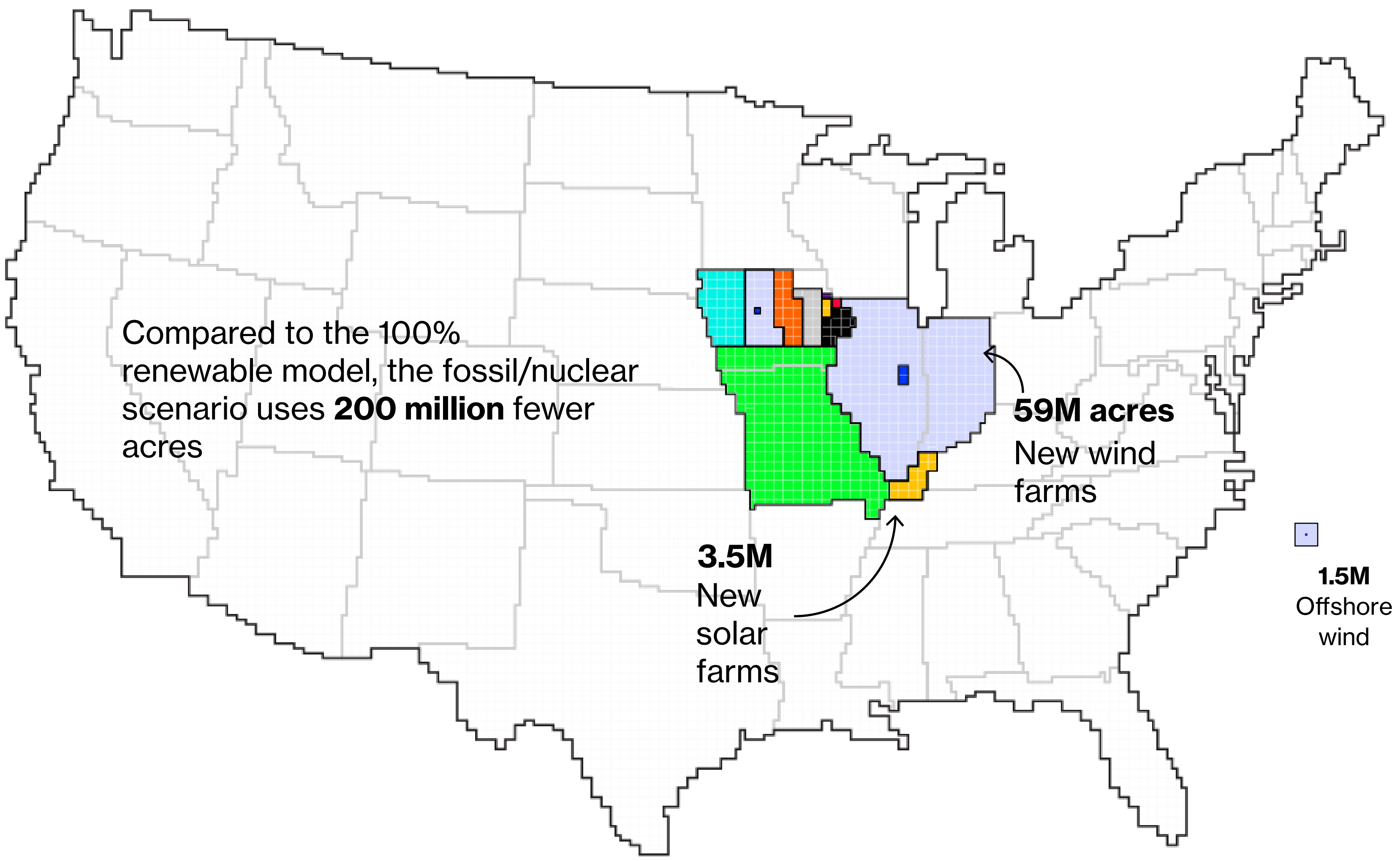
Princeton's study estimates that 11% of electric power could come from offshore wind farms by 2050. Another 3% of generating capacity could come from rooftop solar. In sunnier places, such as California, rooftop solar could generate 74% of electricity, according to the U.S. National Renewable Energy Laboratory.



If the U.S. wants a carbon-free economy by 2050 using the least amount of land, it will need to rely far less on wind and solar and instead build hundreds of nuclear plants and natural gas plants outfitted with systems to capture the carbon dioxide before it escapes into the atmosphere.

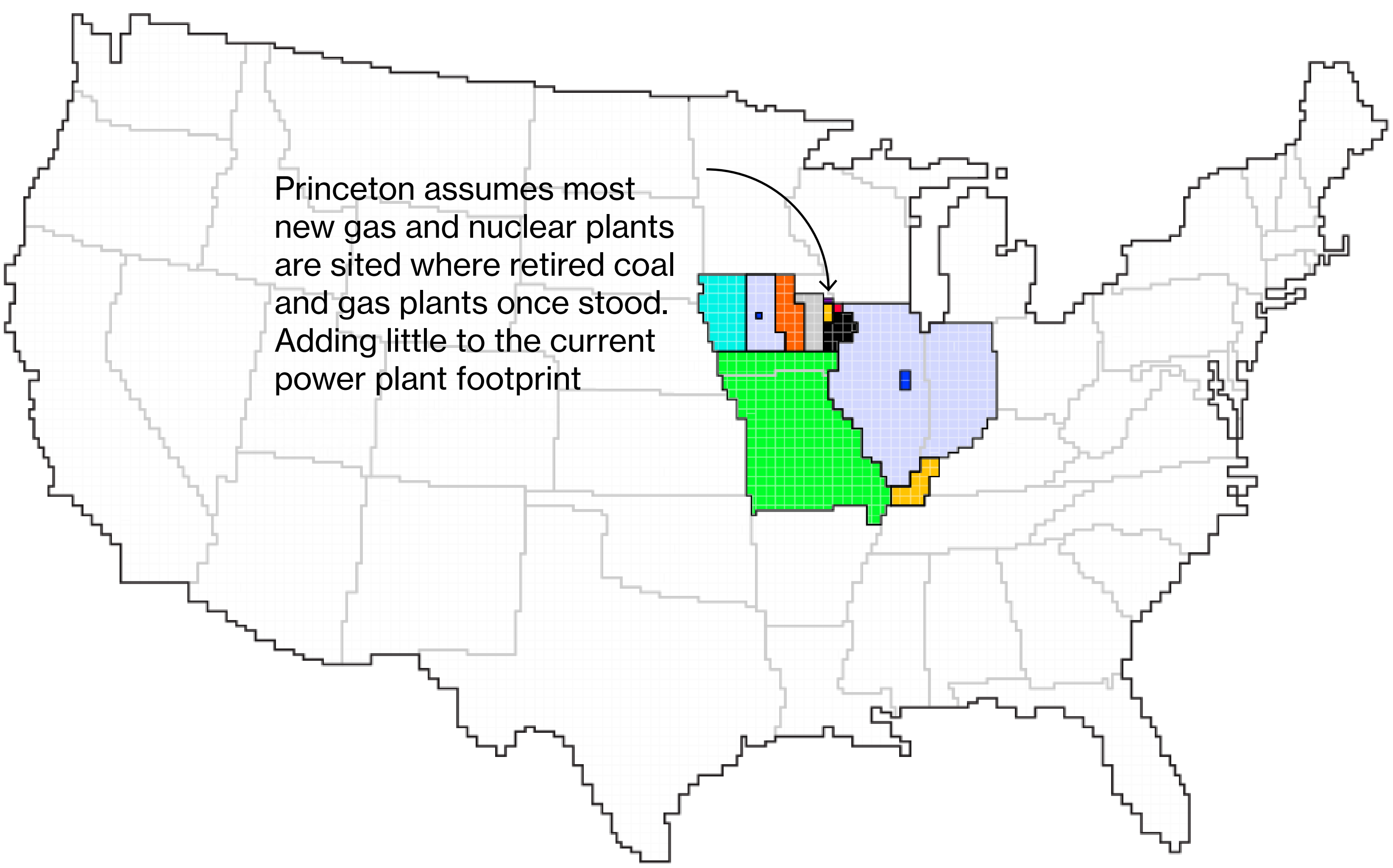


In this model, the current pace of wind and solar development remains constant, but carbon-capture and nuclear power grow at historically unprecedented rates.

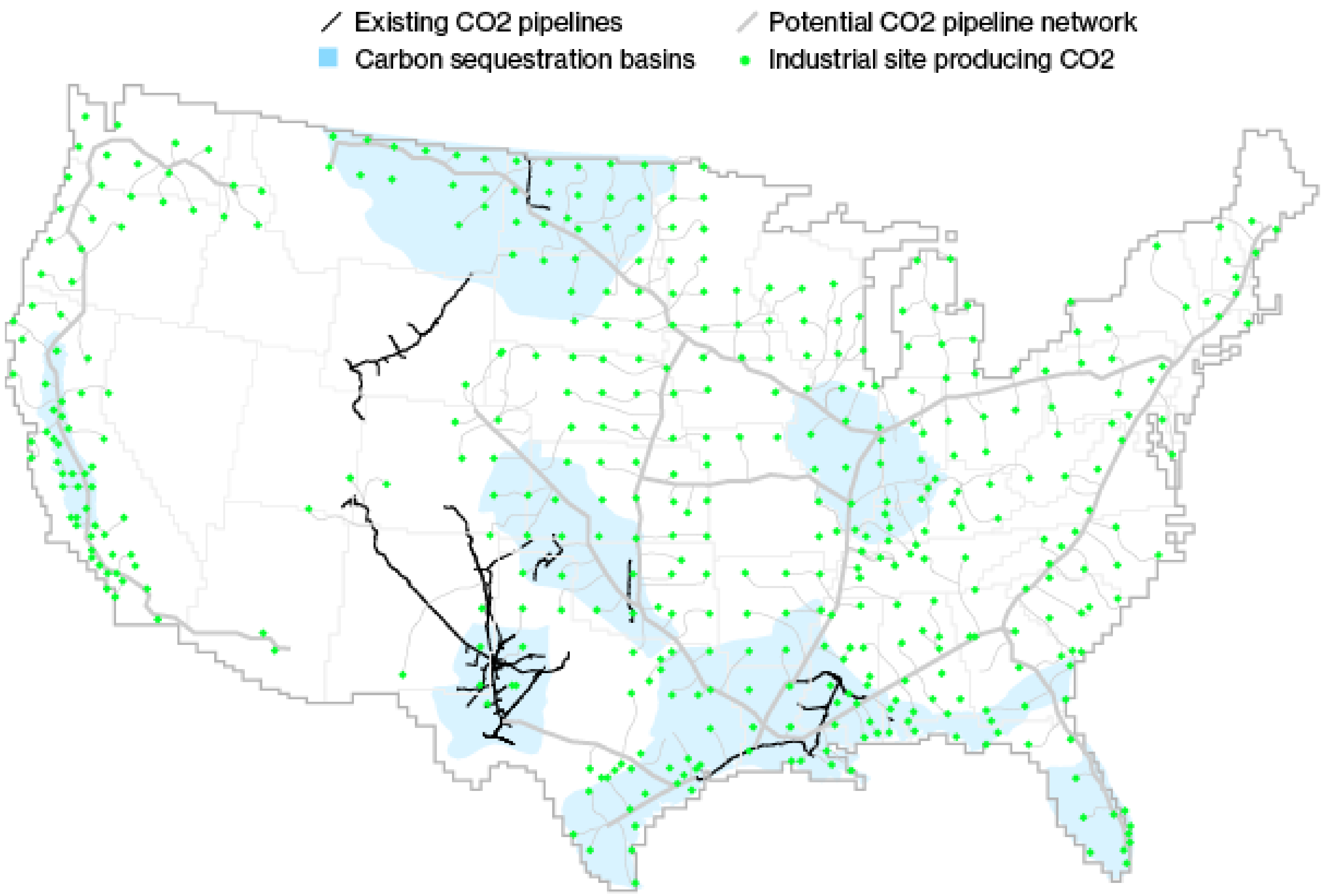



Wind and solar would contribute 44% of electricity generation, and 50% would come from emission-free nuclear and natural gas power plants with carbon-capture technology. Methane, an especially potent emission that's a central component of natural gas, would be aggressively curtailed via better monitoring of pipelines and other equipment. Any leaks would be offset by systems that filter greenhouse gases from the air, improved farming methods and other means.

Under this scenario, the U.S. would need to build 250 nuclear plants with capacity of at least 1 gigawatt, or several thousand smaller modular reactors. Natural gas and nuclear energy are very compact power sources. A conventional 1-gigawatt reactor operating on 1,000 acres produces the same power as a wind farm spanning 100,000 acres.



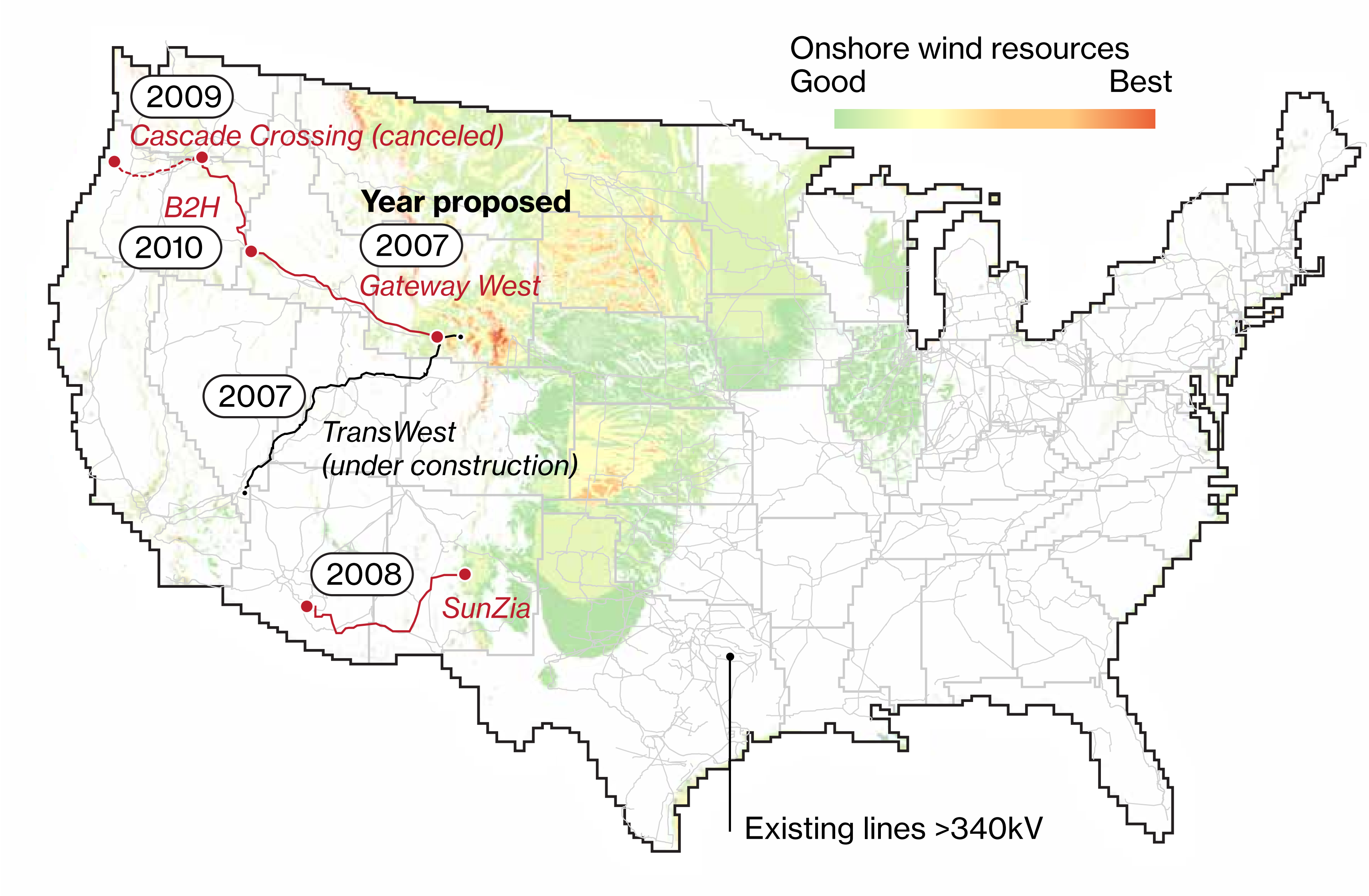

Needless to say, expanding nuclear power will present serious land-use challenges. While no one wants a power plant in their backyard, many people don't want nuclear power on their planet.




To make 300 new natural-gas fired power plants emission-free, a network of carbon-capture pipelines and storage facilities would be built. That would require land easements totaling 500,000 acres, about half the size of Rhode Island. To drive down costs, Princeton estimates it will take about $100 billion in private and public investment in $CO_2$ capture demonstration projects over the next decade.

The most difficult land-use challenge in any scenario may be building transmission lines.

High-voltage transmission line projects




For example, in 2011, former President Barack Obama created the Rapid Response Team for Transmission to speed the permitting of five Western transmission line projects. Only one is under construction so far. Three still face permitting delays. The fifth was canceled.

Transmission line capacity would need to more than triple under the high-renewable scenario laid out by the Princeton researchers. Without it, many new wind and solar projects would be stranded.

Editors: Joe Ryan and Alex Tribou
With assistance from Christopher Cannon

Sources: Princeton University's Net-Zero America project, Jesse Jenkins, Eric Larson; John van Zalk, Paul Behrens, Leiden University; National Renewable Energy Laboratory (NREL); Strata: The Footprint of Energy: Land Use Of U.S. Electricity Production; Energy Information Administration

Methodology: Power efficiency estimates in this article rely on studies by the National Renewable Energy Laboratory, the policy group Strata and "The spatial extent of renewable and non-renewable power generation" by John van Zalk, Paul Behrens, Leiden University. Bloomberg chose the most appropriate estimates based on the different assumptions and methodologies reported by each study.

LAND-USE ESTIMATES

**Onshore natural gas and oil production:** Well acreage for conventional drilling pads and access roads was estimated at 1.5 acre per well, 7 acres for fracked wells (assumes larger well pads, additional traffic, liquid pipelines). 58,000 acres for fracking-sand mines were included per Strata estimates. 110,000 acres for gas processing plants and 2.9 million acres for gas pipeline easements (75-foot wide).

Net energy exports accounted for 3.7% of total U.S. energy production in 2020 according to the Energy Information Administration. Natural gas exports accounted for 8.5% of total U.S. production. Petroleum products net exports were negligible. It is unlikely that specific wells or natural gas production facilities served only energy export customers, so no land-use adjustment was made for gas exports.

Crude oil and petroleum products, such as gasoline, land-use total includes: 639,000 acres for conventional wells, 536,000 for fracked wells, 236,000 acres for refineries and 2 million acres for pipeline easements.

**Fossil-fuel power plants:** 150,000 acres of coal and natural gas power plant footprints are shown separately as that total is used in Princeton scenarios for siting future nuclear and carbon-capture plants.

**Offshore wells** accounted for 0.15% of total U.S. producing gas wells and 0.7% of U.S. oil wells. No land-use acreage was added for offshore facilities.

**Onshore Alaska pipelines and wells** were not included in totals as data comparisons are relative to 1.9 billion U.S. contiguous state acreage. Alaska oil production accounted for 3.8% of U.S. 2019 total.

**Coal:** Coal rail freight is equal to 31.4% of all rail tonnage, only that percentage of total U.S. freight rail mileage was factored and added to coal land-use footprint. Easement widths were calculated at 100 feet for 43,960 miles of track. Coal exports accounted for 16% of U.S. production. Representative land area devoted to exported coal was subtracted from domestic coal mining land footprint. Coal waste storage of 73,000 acres, per Strata estimate, is included in coal footprint.

**Nuclear power:** Most power-plant uranium is mined abroad. The land-use figures are as if uranium is mined and processed domestically. Active power plant acreage was estimated at 832 acres per 1GW capacity by Strata. Waste storage was added for decommissioned plants and four special waste storage sites per Strata estimates.

**Solar power:** Utility scale solar capacity-weighted average is 7.3 acre per megawatt, per NREL. Residential solar panels mounted on rooftops were not added to land-use totals.

**Wind power:** The direct land-use impact of a single wind turbine foundation and access road is estimated at 1 acre per NREL. The indirect impact or spacing requirements of a wind farm — with multiple turbines —necessitates an additional 60 acres per 1MW of turbine capacity per American Clean Power Association estimates.

**Battery storage: I**n Princeton's 2050 highly-electrified scenario, the footprint for battery storage is minimal and not shown. For 186 GW of battery storage capacity in 2050, a Bloomberg footprint estimate is 2,000 acres.

**Power lines:** Land cleared for power line transmission easements are totaled and represented separately and not distributed to each fuel source. Easement widths were calculated at 88 feet for 450,000 miles of high voltage power lines.

**Hydropower:** Hydropower on average needs 305 acres per megawatt capacity per Strata estimates. Reservoirs and switchyards occupy on average 238 acres per megawatt capacity and quarries and gravel pits— that produce aggregate for concrete used in dam construction— use 67 acres. The U.S. capacity of hydropower in 2019 was 28,549 megawatts, for a total of 8.7 million acres needed for hydropower.

**Biomass and biofuels:** Corn for ethanol and soy for biodiesel acreage estimates are from the Feb. 2021, USDA World Agricultural Supply and Demand Estimates.

**Wood biomass and waste:** were not analyzed for this study due to dual-use of land associated with wood biomass and limited growth potential of waste energy.

**Geothermal:** produces less than 0.3% percent of U.S. energy and was not included.

**Raw materials, production processes and waste:** Strata's The Footprint of Energy, examines land use related to infrastructure resource production and waste storage. Coal-waste storage and fracking-sand production, which grow annually, were added to totals. Wind turbine and solar panel manufacturing, and raw material mining processes contributed significantly to acreage land-use per megawatt capacity. But if distributed over the average life-cycle of the power plants was <1% of total land use and was not included.