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The Need to Examine the Life Cycles of All Energy Sources: A Closer Look at Renewable-Energy Disposal

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KEY TAKEAWAYS

The Biden Administration and some lawmakers are moving forward with a historic shift to "zero emissions" energy production without planning for the aftermath.

Renewable-energy advocates focus on zero emissions without considering the materials used in the production of the source or the ultimate disposal of the byproducts.

The government should not intervene in energy markets, including for renewable resources—but since it is, taxpayers deserve a full accounting of costs and benefits.

Every source of energy—including fossil fuels, wind and solar power, and nuclear power—have both positive and negative attributes. Often, proponents or opponents of a certain source gloss over, or hype up, specific challenges or benefits in order to promote their favored solution. In order to make informed decisions about which energy sources can meet America's energy needs, policymakers and the public need to know about the entire life cycle of all energy sources. For example, proponents of fossil fuels often highlight their affordability and reliability, while ignoring the effects of waste disposal or extraction. Likewise, renewable-energy advocates focus on "zero emissions" without considering the materials used in the production of the source or the ultimate disposal of the byproducts or equipment.

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The environmental life cycle of an energy source can be broadly grouped into three categories: (1) the extraction or production of the source material and the equipment required to do so; (2) the generation of the energy and the resulting emissions; and (3) the waste disposal of the byproducts or equipment. All aspects should be considered when evaluating the best energy source for a given use or purpose, including the benefits and the costs for each.

For years, large provisions of U.S. environmental laws, and their corresponding regulations, have been drafted to address the life cycle challenges of fossil fuels. The effectiveness of the laws and regulations must be constantly re-evaluated to ensure that public health and the environment are protected. For example, numerous laws govern oil extraction, the emissions of the refining process, the impact on water quality, and the disposal of waste materials. The natural gas sector is regulated by rules on fracking, extraction, pipeline emissions, and transportation. Coal is regulated, among other ways, through mining restrictions, limits on emissions from power plants, and the closure of coal-refuge ponds. All fossil fuel sources have historically contributed to the creation of large-scale waste sites addressed under the Superfund program for cleanup, and fossil fuels produce air pollution and greenhouse gases.

But as Congress and the Biden Administration, as well as many states, move to limit or reduce the use of fossil fuels in favor of renewable energy, there has been little or no recognition of the negative life cycle consequences of renewable-energy sources, specifically wind, solar power, and electric batteries. Without a full understanding or debate of the issues, decisions made today will create the environmental problems of tomorrow.

All three primary forms of renewable energy—wind turbines, solar panels, and electric batteries—rely on substantial source materials in the production of the equipment. Solar panels and batteries (and to a lesser extent wind turbines), are highly dependent on mining extraction for rare earth minerals and other components, such as arsenic and gallium (for solar panels) and lithium and manganese (for batteries).[1] The production of the fiberglass windmill blades is both energy intensive and requires substantial energy to transport the component parts. The environmental impact of the mining activities, typically in developing countries, are rarely acknowledged or debated, nor are their mining practices considered. Accusations of child labor and the real environmental degradation due to the lack of meaningful environmental laws or standards are often overlooked.[2]

Proponents of renewable energy focus almost exclusively on the positive attributes of its generation, ignoring the equipment-production and waste-disposal issues. The zero emissions of renewable-energy production are unparalleled as an energy source except for nuclear power. There are negative environmental consequences of generation, though, such as bird deaths on windmill farms, and bird and other wildlife deaths attributed to solar panels.[3][4] However, the difference between renewable energy and fossil fuels in terms of air emissions is stark. Unlike conventional carbon-based fuels, renewable-energy technologies typically do not emit nitrogen oxides, sulfur dioxides, mercury, and other air pollutants or greenhouse gases during energy generation.

The remaining category, waste disposal, is absent in most public policy discussions for renewable-energy sources. The issue itself will grow in importance as the use of renewables increases and older equipment reaches the end of its useful life. The rest of this *Backgrounder* examines some of the waste-disposal issues surrounding renewable-energy sources.

Solar Panels

Solar energy use in the United States has grown from five gigawatt hours (GWh) in 1984 to 133,000 GWh in 2020.[5] Solar panels must be installed by specially trained technicians. The panels can be cumbersome to transport and, since principally made of glass, are breakable. The safe removal of the panels also requires specially trained technicians to ensure possible recycling or the more likely scenario of waste disposal without destroying the materials or releasing the hazardous substances contained within the solar panels.

In the United States, materials are classified as hazardous either because they are a listed hazardous waste under federal law and regulations, or they exhibit hazardous characteristics, such as toxicity. Solar panels themselves are not classified as hazardous but are considered hazardous due to their component materials. Solar panels and photovoltaic (PV) modules contain multiple toxic materials including arsenic, cadmium, copper, lead, selenium, silicon, and silver. The inclusion of these hazardous materials in the solar panels triggers the hazardous waste–transportation and waste-disposal regulations and requirements under the 1976 Resource Conservation and Recovery Act.[6] In addition, there are specific regulations tied to the recycling of products containing hazardous materials.[7]

> The inclusion of hazardous materials in solar panels triggers U.S. hazardous waste-transportation and waste-disposal regulations and requirements.

A majority of states allow the disposal of solar panels in municipal landfills.[8] This could create hazardous waste-cleanup issues well into the future depending on the scale and type of the materials involved. California has moved forward with regulations designating solar panel waste as "universal waste," which offers less stringent regulatory requirements for handling and storage and is meant to encourage recycling, which does not always work.[9] Other examples of universal waste include fluorescent light bulbs and some batteries. Washington State has taken the most aggressive approach in dealing with used solar panels by requiring the manufacturers to finance a takeback and recycling system for all panels sold after July 1, 2017.

While large-scale solar facilities are operated by professional companies that, in theory at least, should implement best-case removal practices, the same cannot be said for individual businesses or homeowners. Requirements differ significantly by state or by locality, with most states not regulating the disposal of solar panels at all. With some solar installations expected to last up to 30 years, it is likely that many installations will no longer be owned by the same homeowner or operated by the same business at the end of their life cycle, complicating long-term planning for disposal services. When it is time for the solar equipment to be replaced, the burden could fall on the new installation company or homeowner. The question would remain as to who bears the cost of safely removing and disposing of the older material.

The materials themselves are capable of being recycled, to some extent, however, the cost is currently prohibitive. The cost to recycle one solar panel is approximately $20 to $30 while the cost to dispose of the same panel at a landfill is $1 to $2.[10] The increasing volume of older solar panels reaching the end of their life cycle, coupled with the higher cost of panel recycling, has prompted many within the industry to store old solar panels until the recycling costs are reduced. This, in turn, creates new handling issues if the panels are not stored correctly or degrade significantly over time in storage releasing the toxic materials. One U.S. manufacturer, First Solar, operates a recycling facility in Ohio that can recycle approximately 90 percent of the semiconductor material and glass collected from its used thin-filmed panels.[11]

One of the approaches in the European Union is to hold manufacturers of solar panels responsible for their disposal at the end of their useful life. Under the waste, electrical, and electronic equipment (WEEE) Directive, producers of solar panels are legally responsible for the collection, treatment, and monitoring of the end-of-life management of their solar panels.[12] A similar approach in the United States would be complicated due to the high volume of imported solar panels. According to the National Renewable Energy Laboratory, PV modules and cell imports are at historically high levels despite tariffs imposed by the United States,[13] and Wood MacKenzie reports that 85 percent of solar panels sold in the U.S. are imported.[14] Since many of the foreign manufacturers are Chinese, there is concern that they may not be solvent or in existence in a generation. This may increase the burden on the U.S. installation industry, the property owners, and the disposal and recycling facilities.

The expected volume of the solar-panel waste stream is staggering, considering America's lack of a PV-waste-management system. The International Renewable Energy Agency projects that up to 78 million metric tons of solar panels will have reached the end of their life by 2050, and that the U.S. will be producing 6 million metric tons of new waste annually.[15] It is estimated that around 26,000 tons of solar panels ended up as waste in 2020 alone, and that number is excepted to increase each year.[16] These projections do not take into account the recent accelerated push for solar power by the United States.

> The U.S. waste-stream system is not equipped to deal with a large influx of solar panels today.

In a recent article in the *Harvard Business Review*,[17] the authors report that the combination of the solar tax credits and the year-over-year diminishing performance of older panels will incentivize property owners to replace their older panels at a much faster rate, accelerating the need to dispose of the older panels now as opposed to in the future. The waste-stream system is not equipped to deal with a large influx of solar panels today. If the panels are simply sent to landfills, there is a real possibility of lead and cadmium leaching into the ground water. Likewise, if the panels are stored indefinitely, they could leach out due to degradation or improper storage. The Superfund sites of the past 40 years were mostly created to clean up the damage caused by the improper disposal or storage of historic waste. This country should not repeat those mistakes with renewable sources.

While there have been some limited advances in the recycling of solar panels in the United States, the amount of the material recycled is just a fraction of the amount of waste produced each year. This will grow exponentially as the older solar panels installed in the early 2000s reach the end of their useful life. This end may be artificially accelerating due to the tax code treatment and the development of more efficient solar panels making older panels obsolete before their time. If the U.S. continues to promote greater usage of solar technologies without solving the waste issues, it will merely punt the not-too-distant—and likely overwhelming—environmental problems a bit further down the road.

Wind Turbines

Wind energy in the United States has grown from 40 GWh in 2011 to more than 118 GWh at the end of 2020.[18] While wind turbines are manufactured in several different designs—from the wind turbines found in increasing numbers across the American landscape, to offshore windmills, to small modular units located on buildings.

Wind turbines in general consist of three distinct parts—the tower, the nacelle, and the rotor blades. The tower, generally constructed of steel, stands up to approximately 295 feet tall and weighs around 19,000 pounds. The nacelle, which holds the gears and the main driveshaft, has a fiberglass shell and weighs around 22,000 pounds. The blades are typically made of fiberglass with a hollow core, although there are experimental blades made from lightweight woods and aluminum. The blades are around 50 feet long and weigh around 2,500 pounds. At the base of each tower is a utility box that converts the energy into electricity and is linked to nearby towers through underground pipes to other turbines and a transformer.[19] Offshore wind turbines are even larger and can reach 410 feet with blades of 623 feet.

The average life span of a wind turbine is only about 20 years before the mechanical and structural components decay to the point of replacement, provided there has been consistent maintenance and upkeep over the life span of the turbine.[20] For example, the gearboxes typically must be replaced every eight to 10 years.

Once a turbine has reached the end of its life span, at least in the U.S. market, there are few options for disposal. Some of the parts can be recycled, but the blades themselves, composed of resin and fiberglass, cannot be easily recycled and mostly end up in landfills. Although GE recently announced a deal to start recycling its blades for use in cement manufacturing, it is unknown how quickly the technology can be widely deployed.[21]

Very few landfills in the U.S. can deal with the extremely large turbine blades, which are only getting larger with technological advances.[22] It is projected that at least 8,000 blades will be retired each of the next four years in the U.S.,[23] and landfill owners have begun to experiment with disposal techniques. First, the transportation of the blades is difficult: In order to fit on three semitrucks, each blade must be cut into three pieces using expensive specialty equipment. The two sites with the most blade-cutting experience are in Iowa and Wyoming, and both have struggled with their disposal.[24]

There is an export market for developing countries, and many wind turbines from Europe and some from the U.S. end up in Latin America, Africa, and parts of Asia. While this may seem like a benevolent gesture, the U.S. is selling turbines that are near the end of their life spans to countries that do not have the same waste-management practices as Western countries do, exacerbating global environmental problems.

The U.S. sells aged wind turbines to countries with weak waste-management practices, exacerbating global environmental problems.

A recent study from scientists at the Lawrence Berkeley National Laboratory found a significant drop-off in wind-turbine performance after 10 years—corresponding to the expiration of the wind-energy production tax credit (PTC).[25] Their study suggests that regular maintenance drops off after the PTC expiration makes it less economically viable to pay for the maintenance. If this in fact bears out, wind turbines might have an even shorter life span than expected, resulting in an even larger influx of turbines for disposal in the next few years.

Some states, such as North Dakota, have created a decommissioning policy requiring new wind projects to set aside funds to remove and dispose of old turbines at the end of their life spans.[26] But there is no nationwide policy. Ownership of wind farms differs significantly from ownership of solar panels, since wind farms are predominately owned by large utilities or companies that manage the farms on behalf of utilities as opposed to solar-panel installations, which range in ownership from homeowners to large corporations. Despite the relatively smaller universe of wind-farm owners, in most cases, the financial planning for the disposal of the turbines has not occurred. While the disposal of the turbines does not involve the same level of hazardous materials, the sheer volume of the waste threatens to overwhelm landfills and the disposal process, while the transportation of the components certainly adds negative environmental aspects to the wind-turbine footprint.

Batteries

Battery storage is the key to transforming renewable energy from intermittent to baseload generation. Large-scale battery facilities will be needed to store energy produced at solar and wind farms, and batteries are the key component in making electric vehicles (EVs) feasible.

The large stationary storage facilities built in conjunction with the grid use several different technologies, although more than 90 percent are based on lithium-ion chemistries. (Nickel- and sodium-based batteries account for most of the remaining systems while "flow battery" systems are starting to increase.) In 2010, the U.S. had seven large-scale battery-storage systems accounting for 59 megawatt hours (MWh) of power capacity. By 2018, according to the U.S. Energy Information Administration, the U.S. had 125 systems accounting for 869 MWh of capacity. It is important to note that 53 of the large facilities are co-located with renewable-energy facilities, and that number is expected to double by 2023. Additionally, there is 234 MWh of small-scale storage capacity, with the majority of it in the commercial and industrial sector, and a third in residential properties.[27] The use of large-system and small-system batteries is going to increase quickly over the next few years.

EVs are typically powered with lithium-ion and lithium-polymer batteries. Other types of EV batteries include lead-acid, nickel-cadmium, and nickel-metal hydride. The lithium batteries are very similar in structure to the lithium batteries used in cell phones, computers, and other electronic equipment. The batteries themselves typically contain cobalt, lithium, and nickel, all mined materials, usually from sources outside the U.S.[28] Lithium is mined predominately in Bolivia, Chile, and China. Additionally, the batteries include a number of rare earth minerals, such as neodymium, which is used as part of the motor magnets and mined predominately in China.

EV batteries tend to reach the end of their life cycles with anywhere from 70 percent to 80 percent of their original capacity intact. This is comparable to spent nuclear fuel rods, which maintain up to 80 percent of their fuel capacity when they are discarded. Originally, EV batteries were lead-acid and reached the end of their life after three or four years; over the past 10 years the industry has transitioned to lithium-ion batteries. Today, all electric vehicles sold in the United States come with a warranty of 100,000 miles, or eight years.[29] While in many cases the fine print specifies that in order to be replaced a battery must be unable to hold any charge, some companies will replace the battery if the charge drops below a 70 percent or 60 percent threshold.[30]

A recent study found that EV batteries lose, on average, 2.3 percent of their capacity each year.[31] However, the life span of the battery depends on individual circumstances. Batteries that are charged too often, or depleted to low levels on a regular basis, degrade faster, as does exposure to heat.[32]

Once an EV battery has reached its end of life, the batteries are either repurposed, refurbished, recycled, or disposed. Some companies are looking at ways of repurposing the batteries for uses that do not require a full charge, such as household-generation storage.[33] Others are refurbishing the batteries, a process that entails disassembling the battery pack individually and testing the cells and replacing any needed parts, which is both cumbersome and expensive. Recycling the batteries must be done by a licensed and trained recycler due to the weight, complexity, and toxic components of the batteries.[34] Finally, batteries are disposed of in landfills, which can cause chemical fires and leach chemicals into the groundwater.

Recycling EV batteries consists of several different practices. The most common recycling method is to shred the battery and then separate the metals using pyrometallurgical techniques (burning). This process wastes most of the lithium. The next most common method is hydrometallurgical metal reclamation, which uses a series of acid washes to separate the materials. The third method of EV battery recycling is physical separation, where the components are physically separated using mechanical processes.

> Only a small number of materials can be reclaimed through recycling, and the process is highly energy intensive.

There are byproducts of all three methods, ranging from acids to slag material, and it is important to note that only a small number of materials can be reclaimed, and the processes are very energy intensive. While it is possible to recycle up to 50 percent of the material in batteries, it is estimated that, worldwide, only 5 percent of batteries are recycled.[35] The recycling process is further complicated because the battery electrolyte is flammable, explosive, and highly toxic, and it forms highly corrosive hydrofluoric acid upon contact with water.[36] It is also more expensive to recover lithium through recycling than it is to mine it, further complicating recycling efforts.

According to the International Energy Agency, there were 10 million EVs on the world's roads at the end of 2020.[37] But in the U.S. last year, only 2 percent of new vehicles sold were EVs.[38] President Joe Biden issued an executive order to increase sales of zero-emission vehicles to 50 percent by 2030 as part of his climate goals.[39] This of course means a large influx of EV batteries. Currently there are no requirements in the U.S. to recycle EV batteries, and consumers and manufacturers are left to their own devices. Many EV manufacturers take back the older batteries upon purchase of a new battery, but there is no requirement. Likewise, there is no federal requirement for the manufacturers on whether they recycle or dispose of the used batteries once collected.[40] While California is currently examining potential requirements, policy recommendations are not expected until 2022.[41] With the anticipated increase in EV sales over the next decade it is imperative that decisions are made today about what to do with the coming onslaught of used EV batteries.

The Infrastructure and Jobs Act[42] passed by the U.S. Senate in August 2021 includes significant funding for battery-recycling pilot programs, a voluntary battery-labeling program, and the development of a regulatory framework for recycling batteries. The act does not address the ultimate waste-disposal issues except by stating that the goal of the recycling section is to reduce waste and that the goal of the voluntary labeling section is to reduce safety concerns regarding the improper disposal of batteries.

Ultimately, regardless of recycling or reuse programs, the hazardous materials in the batteries will eventually reach the end of their life and necessitate disposal. Reliance on pilot grants to solve problems in a nascent industry (battery recycling) would be fine, if not for President Biden's national goal of a 50 percent increase in EV sales by 2030. Americans cannot afford to put off the unanswered question of how to dispose of EV batteries at the same time that the federal government is accelerating their deployment.

Conclusion

As a country and as a society, Americans value and depend on affordable and reliable energy—and Americans have never been more dependent on energy than today. In addition to electricity, heating and cooling, and transportation, Americans now rely on personal devices powered by energy, such as smartphones and computers. Yet the Biden Administration, some in Congress, and several states are moving forward with a historic shift in energy production without planning for the aftermath.

Recycling rates of traditional commodities, such as paper, aluminum, glass, and plastics, are at a 20-year low, yet the government would have Americans believe that they will easily be able to recycle renewable-energy materials and byproducts. Recycling PV modules or EV batteries is simply not feasible if the costs are a magnitude larger than the raw materials. This is the same dilemma as with some plastics and glass recycling, where raw materials are cheaper than the recycling process. And, sending old windmills to developing countries under the guise of recycling only prolongs their disposal, burdening underdeveloped governments that are even less equipped to deal with them than is the United States.

U.S. disposal laws, while equipped to deal with toxic materials related to fossil fuel generation, have yet to be tested by the coming deluge of renewable-energy waste. Granted, the laws and regulations for fossil fuels had to catch up with those waste streams, and some of the sites addressed by the 1980 Superfund law dated back to the 19th century. That is no excuse to delay planning for the environmental problems everyone knows are just down the road.

Today, the Biden Administration and Congress are working overtime to incentivize the use of renewable sources, yet they are not proposing solutions to deal with the renewable waste. If the renewable sources would grow organically at their own pace, instead of a forced, almost exponential, growth, there would be more time to plan for their end-of-life disposal. By forcing this rapid expansion of renewable energy, the Biden Administration is creating future problems while turning a blind eye to desperately needed solutions. If the federal government is so aggressively promoting the use of renewable energy through government regulations and subsidies, it should be responsible for ensuring that the waste-disposal issues are addressed.

Renewable energy is a vital part of Americans' future energy mix, but policymakers must not allow the goal of clean emissions to cloud their judgment or close their eyes to the negative environmental impacts. There are no panaceas for America's energy needs, and policymakers and the public must be willing to look at the positives and negatives of all energy sources.

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