

U.S. House Committee on Energy and Commerce
Subcommittee on Environment, Manufacturing, and Critical Materials
“Exposing the Environmental, Human Rights, and National Security Risks of the Biden
Administration’s Rush to Green Policies”
[April 26, 2023]

Documents for the record

At the conclusion of the meeting, the Chair asked and was given unanimous consent to include the following documents into the record:

1. Report from the Institute for Energy Research entitled, “The Economic and Strategic Importance of Domestic Mineral Production” April 24, 2023, submitted by the Majority.
2. Article from The Harvard Gazette entitled, “Benita Kayembe takes hard look at hidden human cost of electric cars” April 25, 2023, submitted by the Majority.
3. Article from Harvard Business Review entitled, “The Dark Side of Solar Power” June 18, 2021, submitted by the Majority.
4. National Mining Association “2023 Mining Facts” April 2023, submitted by the Majority.
5. An article from Rewiring America entitled, “Electrification won’t break the grid, it will make it smarter” Submitted by the Minority.
6. An article from Rewiring America entitled, “Exporting oil and gas does not create energy independence, electrification does.” Submitted by the Minority.
7. A report from the Union of Concerned Scientists entitled, “Driving Cleaner: Electric Cars and Pickups Beat Gasoline on Lifetime Global Warming Emissions.” Submitted by the Minority.
8. A blog from the Union of Concerned Scientists entitled, “Today’s Electric Vehicles Can Greatly Reduce Emissions From Driving.” Submitted by the Minority.
9. A blog from the Union of Concerned Scientists entitled, “Are There Enough Materials to Manufacture All the Electric Vehicles Needed?” Submitted by the Minority.
10. A blog from the Union of Concerned Scientists entitled, “How Much Land Would it Require to Get Most of Our Electricity from Wind and Solar?” Submitted by the Minority.
11. A blog from the Union of Concerned Scientists entitled, “Challenges and Opportunities in Mining Materials for Energy Storage Lithium-ion Batteries.” Submitted by the Minority.
12. A blog from the Union of Concerned Scientists entitled, “What Happens to Wind Turbine Blades at the End of Their Life Cycle.” Submitted by the Minority.
13. A blog from the Union of Concerned Scientists entitled, “Solar Panels Should Be Reused and Recycled. Here’s How.” Submitted by the Minority.
14. A fact sheet from Earthjustice entitled, “Building a Sustainable Mineral Supply Chain For a Clean Energy Economy.” Submitted by the Minority.
15. A fact sheet from Zero Emission Transportation Association entitled, “Electric Vehicle Factsheet.” Submitted by the Minority.

16. A report from Climate Power entitled, "Clean Energy Boom." Submitted by the Minority.
17. A report from Climate Power entitled, "The Clean Energy Boom in House Republican Districts," submitted by Ranking Member Frank Pallone, Jr.
18. A Politico article entitled, "Big Winners from Biden's Climate Law: Republicans Who Voted Against It." Submitted by the Minority.
19. An article from CleanTechnica entitled, "Want to Electrify Everything? Train More Electricians—Quickly" Submitted by the Minority.
20. A report from Rewiring America entitled, "Mobilizing for a Zero Carbon America: A Jobs and Employment Study Report." Submitted by the Minority.
21. A blog from the Union of Concerned Scientists entitled, "Are EV Batteries Recyclable?" Submitted by the Minority.
22. A blog from the Union of Concerned Scientists entitled, "Battery State of Health—What is it? Why is it Important?" Submitted by the Minority.
23. A blog from the Union of Concerned Scientists entitled, "California's Progress Toward Recycling Policy for EV Batteries." Submitted by the Minority.
24. A blog from the Union of Concerned Scientists entitled, "What Can We Learn From the EU Battery Law?" Submitted by the Minority.
25. A blog from the Union of Concerned Scientists entitled, "Guiding Principles for EV Battery Recycling Policy." Submitted by the Minority.
26. A blog from the Union of Concerned Scientists entitled, "Why Do We Need EV Battery Recycling Policy?" Submitted by the Minority.
27. A blog from the Union of Concerned Scientists entitled, "Why New DOE Battery Recycling and Repurposing Investments Are Crucial to the Future of EVs." Submitted by the Minority.

The Economic and Strategic Importance of Domestic Mineral Production

Unlocking the Value of America's
Homegrown Mineral Resources

Prepared by

Institute for Energy Research

1155 15th St. NW, Suite 525

Washington, D.C. 20005

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INTRODUCTION

The world's energy systems are constantly changing. Over the last three hundred years dramatic shifts in technology have advanced the way we produce and use energy. We saw crude oil replace whale oil for lighting and then electricity replace oil. Over a hundred years ago, gasoline and electric vehicles competed to produce the motive power of automobiles. Gasoline won out, but emerging technologies along with government programs have sparked a new competition between gasoline and electric-powered vehicles. For electricity generation in the United States, we have seen the dominance and then decline of coal generation, the advent of nuclear power, a rapid increase in natural gas-fired generation, and a push by federal and state governments to increase the production of wind and solar-generated electricity.

As we look to the future, improvements in technology and increased government involvement in energy markets means we will likely see more electric vehicles (EVs), batteries for storage, solar panels, wind turbines, and increased competitiveness of hydrogen technologies. In addition to improvements in technology, many governments and some businesses around the world are trying to set targets to reach net zero carbon dioxide emissions, which means reducing carbon dioxide emissions to as close to zero as possible so that any remaining emissions are reabsorbed from the atmosphere by oceans, forests, or other plants.¹ The Biden administration, for example, has set a goal for the U.S. to achieve net zero carbon dioxide emissions by 2050.

One of the major impediments to net zero goals and the continued rollout of many of the energy technologies that would help reach them is that they require far more minerals and materials than are currently being produced. As the International Energy Agency (IEA) explains:

An energy system powered by clean energy technologies differs profoundly from one fueled by traditional hydrocarbon resources. Solar photovoltaic (PV) plants, wind farms, and electric vehicles (EVs) generally require more minerals to build than their fossil fuel-based counterparts. A typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired plant. Since 2010 the average amount of minerals needed for a new unit of power generation capacity has increased by 50 percent as the share of renewables in new investment has risen.²

According to the IEA's "sustainable development scenario," these new energy technologies will require a 42-fold increase in lithium demand, a 25-fold increase in graphite demand, a 21-fold increase in cobalt demand, a 19-fold increase in nickel demand, and a 7-fold increase in rare earth demand by 2040 to meet carbon dioxide emissions goals set by some governments around the world.³

New mining projects are not projected to keep up with this incredible increase in demand. For example, EV expert Steve Levine recently argued that "the EV industry is in a decades-long battery metals crisis."⁴ He went on to explain that in 2022, lithium and nickel production only support



1 United Nations, Climate Action: For a livable climate: Net-zero commitments must be backed by credible action, <https://www.un.org/en/climatechange/net-zero-coalition>

2 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 2021, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>

3 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 2021, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>

4 Steve LeVine, Twitter, Apr. 26, 2022, https://twitter.com/stevelevine/status/1518913709397131264?s=20&t=VDBSMrbUvCUswbzKJGU_fQ

the production of 3.8 million pure EVs, however, automakers said they wanted to make 7.7 million EVs in 2022.⁵ Levine used major metals production forecasts and calculated that by 2030 there will only be enough lithium and cobalt for 15.6 million EVs, while automakers say they want to produce over 40 million in 2030.⁶ What makes this situation even more unrealistic is that demand for lithium-ion batteries is not just coming from EVs, but also storage on the electrical grid made necessary by part-time renewable energy sources being mandated and subsidized into the system.

Not only are there projected shortages for minerals and materials used for EVs and batteries, but there is a massive project shortfall in necessary copper production as some of the world's largest copper mines have operated for more than a century. S&P Global recently released a report which found that "Unless massive new [copper] supply comes online in a timely way, the goal of net zero emissions by 2050 will be short-circuited and remain out of reach."⁷ S&P Global projects that copper demand would have to double between now and 2035 to meet the goal of net zero by 2050.

The increase in demand for these minerals and materials is already putting upward pressure on prices. According to Benchmark Minerals Intelligence, from April 2021 to April 2022, the raw materials that constitute NCM (nickel, cobalt, magnesium) lithium-ion batteries have increased in price by 164 percent, and the raw materials that make-up lithium-ion phosphate batteries have increased by 393 percent.⁸

The problem is not just with minerals and materials shortages, but energy security as well. Russia's leverage over Europe due to its dependence on Russian oil and natural gas is a reminder of the importance of energy security. The United States Geological Survey (USGS) recently estimated that there were 50 minerals critical to the security of the United States. In 2021, imports comprised more than half of the U.S. consumption for 47 of these mineral commodities, and the U.S. was 100 percent net import reliant for 17 of them.

It's not just the U.S. As the IEA has stated, "the production of many energy transition minerals today is more geographically concentrated than that of oil or gas."⁹ The processing of these minerals is even more.¹⁰ China is the largest processor of copper, nickel, cobalt, lithium, and rare earth—processing between 35 percent and 85 percent of these minerals.

At the moment, the United States and the rest of the world are utterly dependent on China to meet the growing demand for critical minerals and materials necessary for our energy. That doesn't have to be the case in the future. Over the last 15 years, the United States changed the world's energy landscape by dramatically increasing our production of oil and natural gas. In 2012, President Obama would tell anyone who would listen that it was "stupid" to think that the United States could lower oil prices by drilling for more oil.¹¹ He argued that "drill, baby, drill" was just a bumper sticker and wouldn't work.

President Obama was wrong. Drill, baby, drill—or simply access to and the production of our vast oil and gas resources—was an energy strategy that worked to lower oil, gasoline, and natural gas prices. Over the past decade, U.S. oil production doubled. Not only that, but the United States became the largest liquefied natural gas (LNG) exporter to Europe, enabling Europe to do without Russian natural gas. Europe's energy crisis would be far worse without the U.S. ramp-up in exports of LNG.

Just as "drill, baby, drill" worked for oil and natural gas production, "mine, baby, mine" can work for minerals. However, the Biden administration is working to stifle any new mining in the United States. Just to name a few examples, the Biden administration has stymied development of the Twin Metals and Polymet mines in Minnesota, the Resolution and Rosemount mines in Arizona, and the Pebble Mine in Alaska. They have also reduced access to the Ambler Mining District in Alaska. The Biden administration has been more disposed toward lithium mines, such as Rhyolite Ridge and Thacker Pass, but actual construction has only begun at Thacker Pass.

If the Biden administration wants to achieve its net zero goals, it should be aggressively working to open more mines in the United States as well as improving our processing capabilities. But they are not. It is possible that the Biden administration hates new mines more than they hate new oil and gas production.

We need a path forward to enable entrepreneurs to do for minerals what they have done for U.S. production of oil and natural gas. In essence, we need to "mine, baby, mine."

5 Globally, EV makers sold about 7.6 million battery electric vehicles in 2022. What accounts for the difference? Levine is modeling a standard battery pack. He has explained, "The estimates are pure EVs, not with hybrids, and a standard 90kWh battery. When you use a different mix, such as 55kWh or 75kWh, you can get more production. But the message is the same: lithium and nickel are limiting factors in how many EVs will be made this decade."

6 Steve LeVine, Twitter, Apr. 24, 2022, <https://twitter.com/stevelevine/status/1518378692254310401>. See also Steve LeVine, Just How Many EVs Can Be Made? Far Fewer Than Expected, The Electric from The Information, Apr. 24, 2022, <https://subscriptions.theinformation.com/newsletters/the-electric/archive/just-how-many-evs-can-be-made-far-fewer-than-expected>

7 S&P Global, The Future of Copper: Will the looming supply gap short-circuit the energy transition?, p. 9.

8 Simon Moore's, <https://twitter.com/sdmoores/status/1518680838057213952>

9 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 2021, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>

10 Ibid.

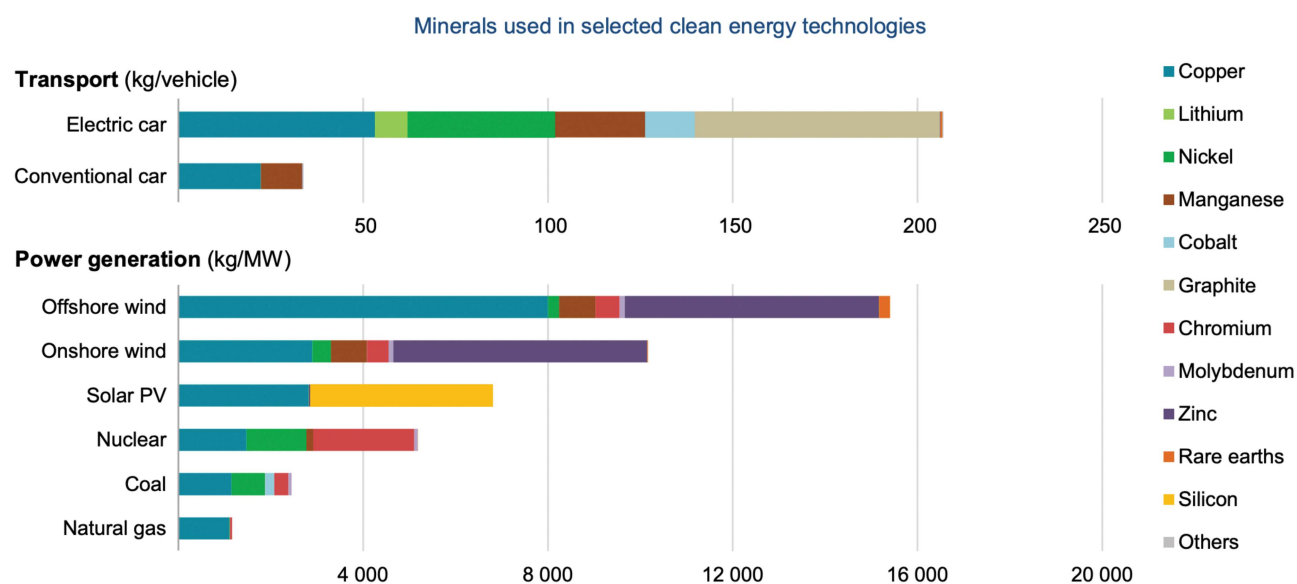
11 President Barack Obama, Obama: 'The American People Aren't Stupid', Feb. 23, 2012, speech at the University of Miami, <https://www.youtube.com/watch?v=wyFX2iM-dSE&ab>

THE MASSIVE MINERAL AND MATERIALS REQUIREMENTS FOR WIND, SOLAR, AND EVS

There has been a lot of talk of an energy transition away from oil, natural gas, and coal and toward wind, solar, and EVs. The IEA calls this a “shift from a fuel-intensive to a material-intensive energy system.”¹² This new energy system would differ profoundly from the current one fueled by traditional hydrocarbon resources.

For example, a typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired power plant. In fact, because of the addition of new wind and solar capacity, since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50 percent.¹³

The rapid deployment of clean energy technologies as part of energy transitions implies a significant increase in demand for minerals



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included.

Source: [International Energy Agency: The Role of Critical Minerals in Clean Energy Transitions](https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf)

12 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 5, 2021, at 28, <https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf>

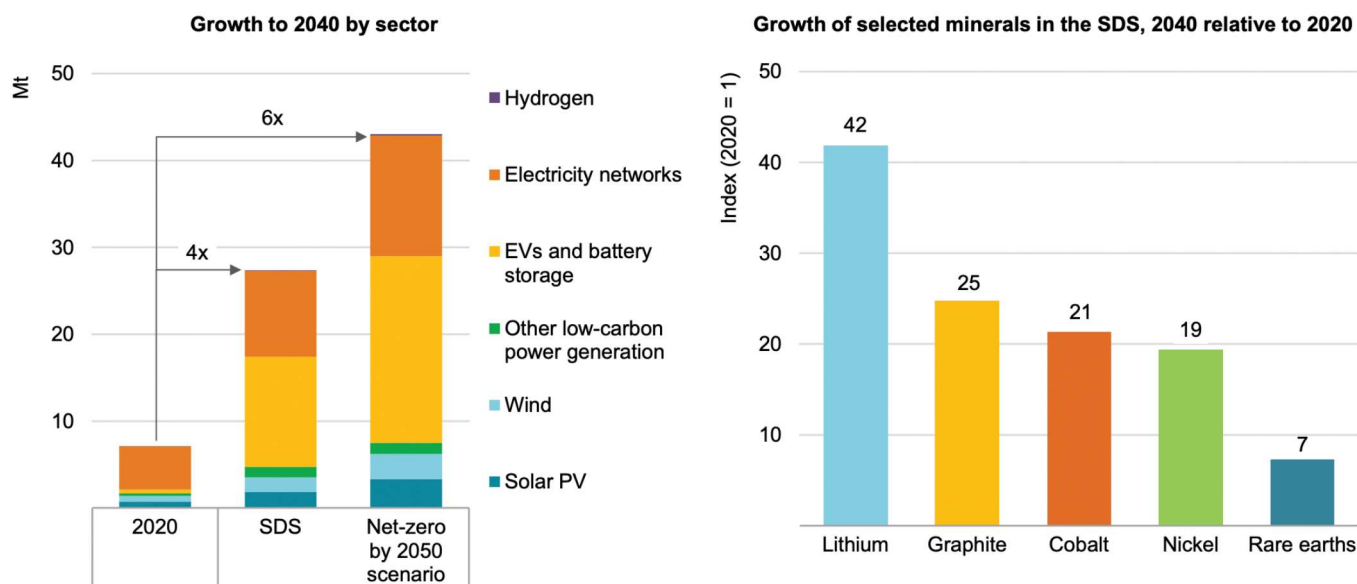
13 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 5, 2021, <https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf>

As IEA shows below, its sustainable development scenario results in a 42-fold increase in lithium demand, a 25-fold increase in graphite demand, a 21-fold increase in cobalt demand, a 19-fold increase in nickel demand, and a 7-fold increase in rare earth demand by 2040.¹⁴

The Biden administration is seeking to mandate that 50 percent of new car sales in 2030 be electric, a carbon-free electric grid by 2035, and a carbon-free U.S. economy by 2050. These requirements would put an enormous demand on mining and manufacturing companies for critical minerals and their resulting products. The United States currently has little extraction and processing capability to meet these future demands. The USGS recently estimated that there were 50 minerals critical to the security of the United States. In 2022, imports made-up more than half of the U.S. consumption for 50 of these mineral commodities, and the U.S. was 100 percent net import reliant for 15 of them.

Mineral demand for clean energy technologies would rise by at least four times by 2040 to meet climate goals, with particularly high growth for EV-related minerals

Mineral demand for clean energy technologies by scenario



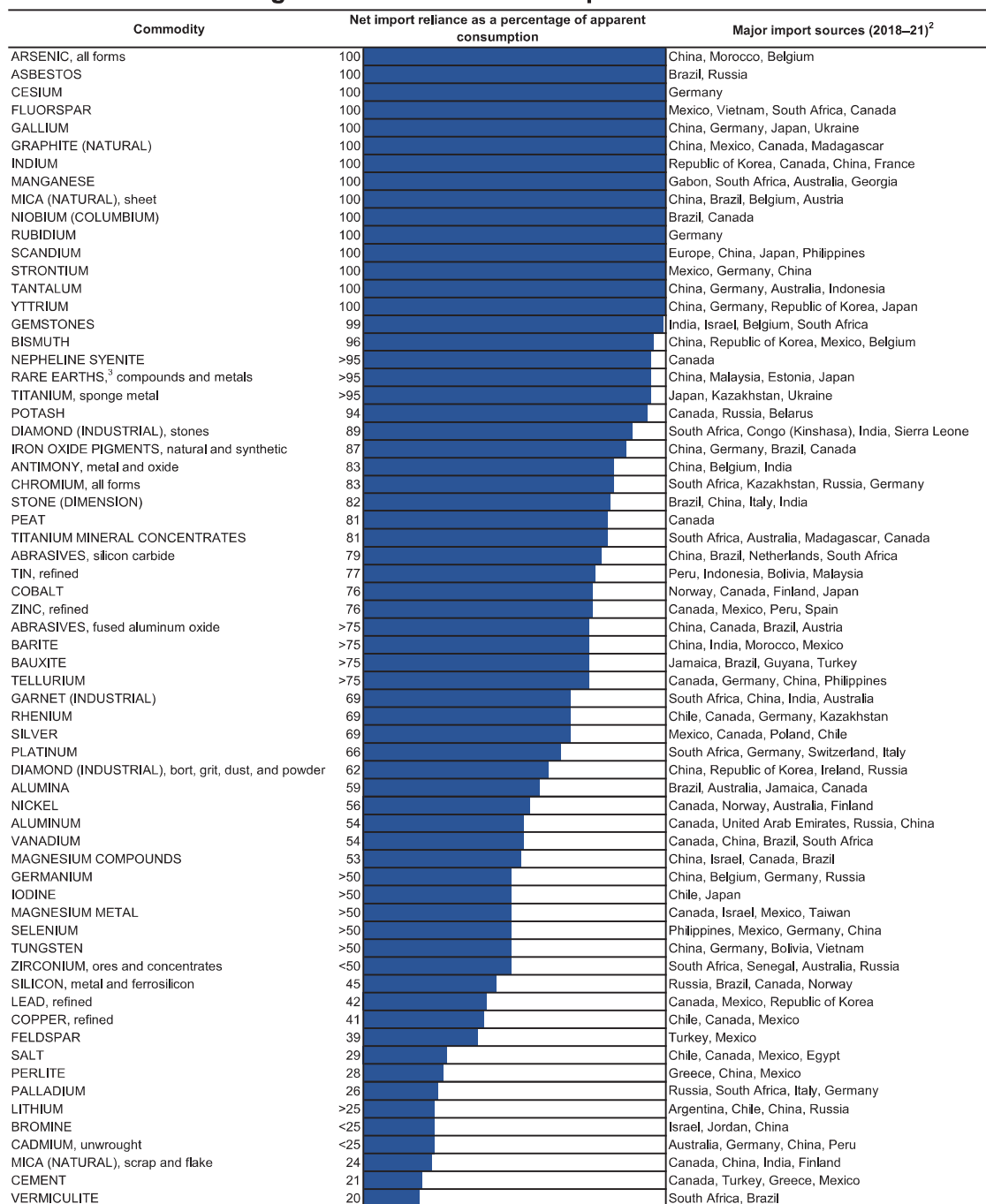
Notes: Mt = million tonnes. Includes all minerals in the scope of this report, but does not include steel and aluminium.

Source: [International Energy Agency: The Role of Critical Minerals in Clean Energy Transitions](https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions)

¹⁴ International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 2021, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>

Figure 2 illustrates the reliance of the United States on foreign sources for raw and processed mineral materials.¹⁵

Figure 2.—2022 U.S. Net Import Reliance¹



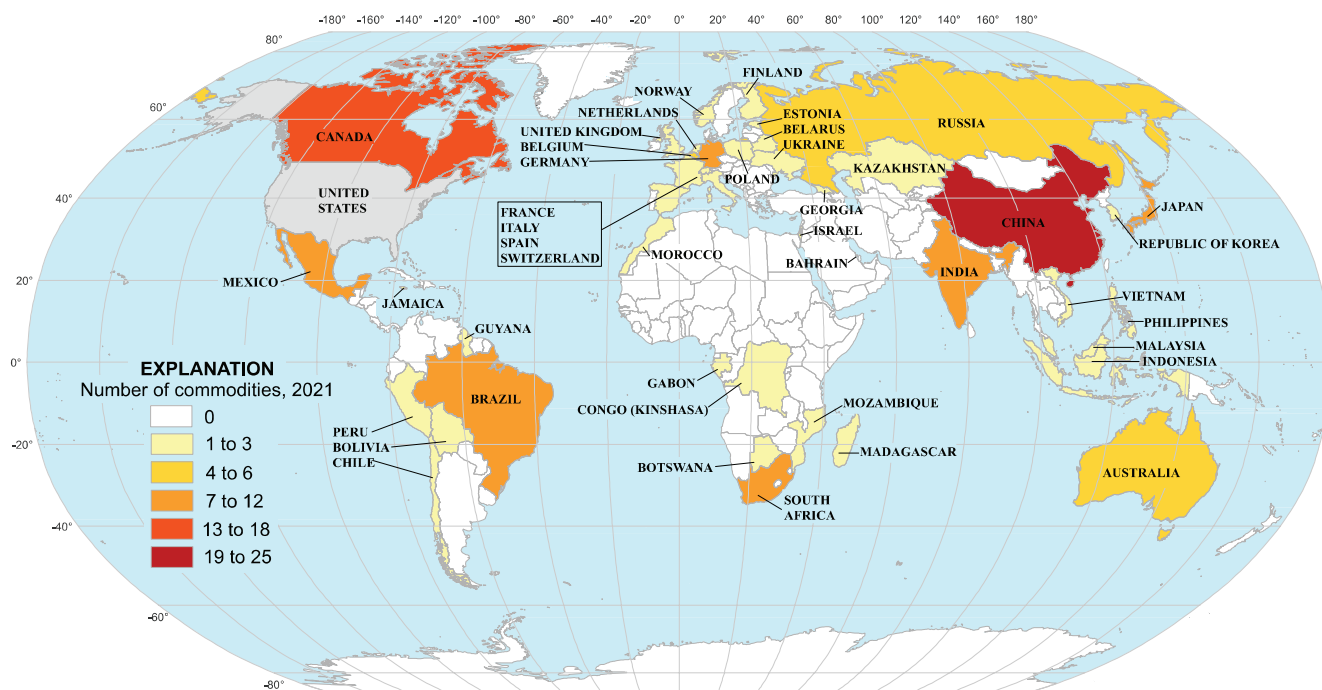
¹Not all mineral commodities covered in this publication are listed here. Those not shown include mineral commodities for which the United States is a net exporter (abrasives, metallic; boron; clays; diatomite; gold; helium; iron and steel scrap; iron ore; kyanite; molybdenum; rare earths, mineral concentrates; sand and gravel, industrial; soda ash; titanium dioxide pigment; wollastonite; zeolites; and zinc, ores and concentrates) or less than 20% net import reliant (beryllium; gypsum; iron and steel; iron and steel slag; lime; nitrogen (fixed)—ammonia; phosphate rock; pumice and pumicite; sand and gravel, construction; stone, crushed; sulfur; and talc and pyrophyllite). For some mineral commodities (hafnium; mercury; quartz crystal, industrial; thallium; and thorium), not enough information is available to calculate the exact percentage of import reliance.

²Listed in descending order of import share.

³Data include lanthanides.

Figure 3 shows the countries that were sources of mineral commodities for which the United States was greater than 50 percent net import reliant in 2022 and the number of mineral commodities for which each highlighted country was a leading supplier. China, followed by Canada, supplied the largest number of these mineral commodities. The countries that were the leading sources of imported mineral commodities with greater than 50 percent net import reliance were: China (26); Canada (20); Germany (14); Brazil (11); South Africa (10); and Mexico (9).¹⁶

Figure 3 — Major Import Sources of Nonfuel Mineral Commodities for which the United States was Greater than 50% Net Import Reliant in 2021



Source: [U.S. Geological Survey](#) Mineral Commodities Summaries 2023

Import dependence on these critical minerals is problematic because it can put supply chains, U.S. companies, and mineral users at risk, particularly when China dominates the mineral supply chains and most of the world's mineral processing.

GREEN ENERGY RUNS THROUGH COMMUNIST CHINA

For years many people and organizations argued that the United States needed to reduce its fossil fuel use to reduce dependence on Middle Eastern oil. Since 2019, however, the United States has been essentially self-sufficient in oil production.¹⁷ Nevertheless, some of the same people and groups now want the United States to ignore this fact and transition to electric vehicles. The problem is that the minerals and materials required for EVs, battery storage, and renewables are much more geographically concentrated than oil production is. A single country, China, dominates these supply chains. Even if China were a trustworthy trading partner, which it is not, this would still be a problem because it creates a near-total supply chain dependence on one single country.

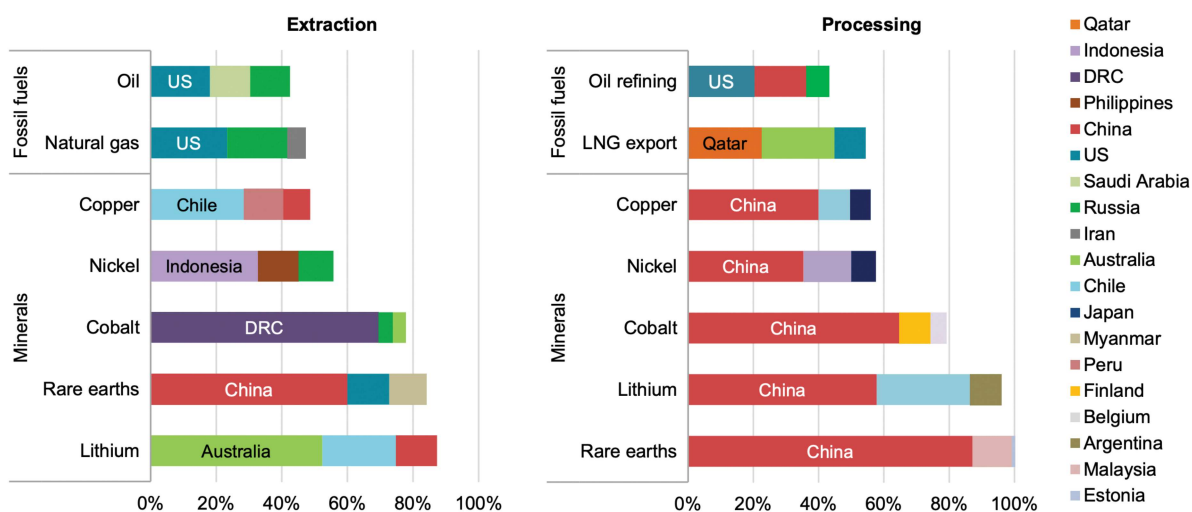
Due to its massive and cheap coal generation, China processes and refines most of the world's critical minerals. Where it does not have domestic raw materials, China invests in them around the world, most notably in Africa, South America, and Asia. China is even invested in the Mountain Pass rare earth mine in the United States.

The world's top three producing nations control well over three-quarters of the global output of lithium, cobalt, and rare earth elements. In 2019, the Democratic Republic of the Congo and the People's Republic of China were responsible for 70 percent and 60 percent of the global production of cobalt and rare earth elements, respectively.¹⁸ For processing operations, China's involvement was and continues to be even higher. China's share of refining is around 35 percent for nickel, 50 to 70 percent for lithium and cobalt, and almost 90 percent for rare earth elements.¹⁹ That

A single country, China, dominates these supply chains. Even if China were a trustworthy trading partner, which it is not, this would still be a problem because it creates a near-total supply chain dependence on one single country.

Production of many energy transition minerals today is more geographically concentrated than that of oil or natural gas

Share of top three producing countries in production of selected minerals and fossil fuels, 2019



Notes: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations.

Source: [International Energy Agency](#) World Energy Outlook Special Report

17 See Energy Information Administration, 4-Week Avg U.S. Net Imports of Crude Oil and Petroleum Products (Thousand Barrels per Day), <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=p&s=wtntus2&f=4>

18 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 5, 2021, <https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf>

19 Ibid.

means “green” energy runs through Communist China. Chinese companies have made substantial investments in overseas assets in Australia, Chile, the Congo, and Indonesia. China’s investments and huge role in processing and refining critical minerals increase the risks that could arise from physical disruption, trade restrictions, or other global developments. For example, in 2010, China cut its rare earth exports by 40 percent and cut off supplies to Japan over a territorial dispute, causing prices to soar.²⁰

In 2019, Chinese chemical companies accounted for 80 percent of the world’s total output of raw materials for advanced batteries.²¹ China controls the processing of almost all the critical minerals—rare earth, lithium, cobalt, and graphite. Of the 136 lithium-ion battery plants in the pipeline to 2029, 101 are based in China. The largest manufacturer of electric vehicle batteries, with a 27.9 percent market share, is China’s Contemporary Amperex Technology Co. Ltd founded in 2011.

RARE EARTHS

Rare earth elements are a bit of a misnomer. Rare earths are not that rare in the earth’s crust. However, they can only usually be found in small concentrations and are often bonded to other, more abundant, mineral deposits. The biggest challenge with rare earths is the processing required to separate rare earths from other minerals. These separations can be environmentally damaging if costly techniques are not used. Expensive environmental control technology is one reason less rare earth separations are done in the United States over the past few decades and more are done in China. China is one of the world’s leaders in rare earth separations on an industrial scale.



Rare earth elements and minerals loaded on cargo ship in China.

Worldwide reserves of rare earths total about 120 million metric tons.²² Of that amount, 44 million metric tons, or 34 percent, are located within China. After China, the major rare earth countries based on reserve volume are Vietnam, Brazil, and Russia. The United States also has some reserves, estimated at 1.8 million metric tons. In 2022, China was the world’s largest producer of rare earths, producing 210,000 metric tons, or 70 percent of the world’s production.²³ While China produces most of its rare earths in the southeastern part of the country, in the provinces Jiangxi and Fujian, rare earth production also occurs in Inner Mongolia and Sichuan. In 2022, the United States produced about 43,000 metric tons of rare earth minerals—a fifth of what China produced.²⁴ Those minerals were almost exclusively processed into end materials in China.

In addition to rare earths, the manufacturing of lithium-ion batteries depends on key materials like graphite, cobalt, manganese, and nickel. In 2022, China produced 65 percent of the world’s graphite and has 16 percent of the world’s reserves.²⁵

COBALT

China has only 2 percent of the world’s cobalt reserves,²⁶ but China owns eight of the 14 largest cobalt mines in the Democratic Republic of Congo, and they account for about half of the country’s output.²⁷ China dominates in the processing of raw cobalt, where raw material is turned into commercial-grade cobalt metal, refining over 80 percent of the world’s product. An American company once owned the largest mine in the Congo, but sold it in 2016 to China Molybdenum.

20 Institute for Energy Research, Rare Earth Elements: What Are They? Who Has Them?, July 27, 2016, <https://www.instituteforenergyresearch.org/renewable/rare-earth-elements/>

21 Voa News, How China Dominates Global Battery Supply Chain, September 1, 2020, https://www.voanews.com/a/silicon-valley-technology_how-china-dominates-global-battery-supply-chain/6195257.html

22 Statista, Reserves of Rare Earths Worldwide, as of 2022, February 28, 2023, <https://www.statista.com/statistics/277268/rare-earth-reserves-by-country/>

23 Ibid.

24 Ibid.

25 U.S. Geological Survey, Mineral Commodity Summaries 2023, <https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf>

26 Ibid.

27 Voa News, How China Dominates Global Battery Supply Chain, September 1, 2020, https://www.voanews.com/a/silicon-valley-technology_how-china-dominates-global-battery-supply-chain/6195257.html

LITHIUM

China is among the top five countries with the most lithium resources,²⁸ and it has been buying stakes in mining operations in Australia and South America, where large lithium reserves are located. China's Tianqi Lithium owns 51 percent of the world's largest lithium reserve in Australia.²⁹ In 2018, the company became the second-largest shareholder in Sociedad Química y Minera—the largest lithium producer in Chile.³⁰ Another Chinese company, Ganfeng Lithium, has a long-term agreement to underwrite all lithium raw materials produced by Australia's Mount Marion mine—the world's second-biggest, high-grade lithium reserve.³¹ In 2022, China produced 15 percent of the world's lithium, having 8 percent of the world's lithium reserves.³²

MANGANESE

China mined only about 5 percent of the world's manganese in 2022,³³ but refined over 90 percent of it.³⁴ Most manganese supply is concentrated in South Africa, followed by Gabon and Australia. North America produces very little manganese.

NICKEL

Unlike the other minerals, the nickel mining industry is more evenly spread around the world, but China controls most of the chemical processing.³⁵ Indonesia, due to on-again off-again ore bans, has in the past caused volatility in the nickel market. However, in 2022, it produced 48 percent of the world's total nickel production, about 54 percent more than in 2021, and it has 20 percent of the world's reserves.³⁶ Russia produced 7 percent of the world's nickel and has 8 percent of the world's reserves.³⁷ Electric vehicles account for about 7 percent of overall nickel consumption today,³⁸ but that would skyrocket under plans to electrify vehicles as proposed by President Biden and several leaders of western countries.

COPPER

Copper is another example of a mineral where it looks like demand will far outstrip supply. S&P Global recently released a study calling copper the "metal of electrification." They found:

The study seeks to quantify the amount of additional copper that will be required by increased electrification and the energy transition—most specifically, the rapid move to electric vehicles (EVs) and renewable electricity and the need for increased electricity infrastructure. It concludes that copper demand will double by 2035 and continue to grow thereafter. On the supply side, it finds how challenging that will be, whether on the basis of current trends or with an unprecedented acceleration of supply from mining and recycling.



Large scale mining of copper in central Chile, region of Coquimbo.

28 U.S. Geological Survey, Mineral Commodity Summaries 2023, <https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf>

29 Voa News, How China Dominates Global Battery Supply Chain, September 1, 2020, https://www.voanews.com/a/silicon-valley-technology_how-china-dominates-global-battery-supply-chain/6195257.html

30 Fuels and Lubes, Tianqi Lithium's purchase of SQM shares would make Chinese firm world's largest producer of lithium, May 24, 2018, <https://www.fuelsandlubes.com/tianqi-lithiums-purchase-of-sqm-shares-would-make-chinese-firm-worlds-largest-producer-of-lithium/>

31 SMM News, the sale of shares in the Australian mine involves 57000 tons of lithium concentrate Ganfeng lithium industry to obtain half of the shares, December 21, 2018, <https://news.metal.com/newscontent/100913083/%5bsmm-express%5d-the-sale-of-shares-in-the-australian-mine-involves-57000-tons-of-lithium-concentrate-ganfeng-lithium-industry-to-obtain-half-of-the-shares/>

32 U.S. Geological Survey, Mineral Commodity Summaries 2023, <https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf>

33 Ibid.

34 Mining, China's stranglehold on electric car battery supply chain, April 16, 2020, <https://www.mining.com/chart-chinas-stranglehold-on-electric-car-battery-supply-chain/>

35 Ibid.

36 U.S. Geological Survey, Mineral Commodity Summaries 2023, <https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf>

37 Ibid.

38 Mining, China's stranglehold on electric car battery supply chain, April 16, 2020, <https://www.mining.com/chart-chinas-stranglehold-on-electric-car-battery-supply-chain/>

One possible challenge to the future copper supply is the new government of Chile. Chile is the largest copper-producing country in the world, but has recently installed a socialist government. The new government has proposed to increase taxes on mining and possibly to nationalize mining companies. So far, the latter has not worked. BHP Billiton, which operates the world's largest copper mine, is reconsidering investments in Chile.³⁹

CHINESE CONTROL OF PROCESSING

A study by KU Leuven University shows that meeting the European Union's Green Deal goal of "climate neutrality" by 2050 will require 35 times more lithium and 7 to 26 times the amount of rare earth metals compared to Europe's current use.⁴⁰ According to the study, besides the increase in lithium and rare earth metals, Europe's energy transition will also require 30 percent more aluminum than what is used currently, 35 percent more copper, 45 percent more silicon, 100 percent more nickel, and 330 percent more cobalt.

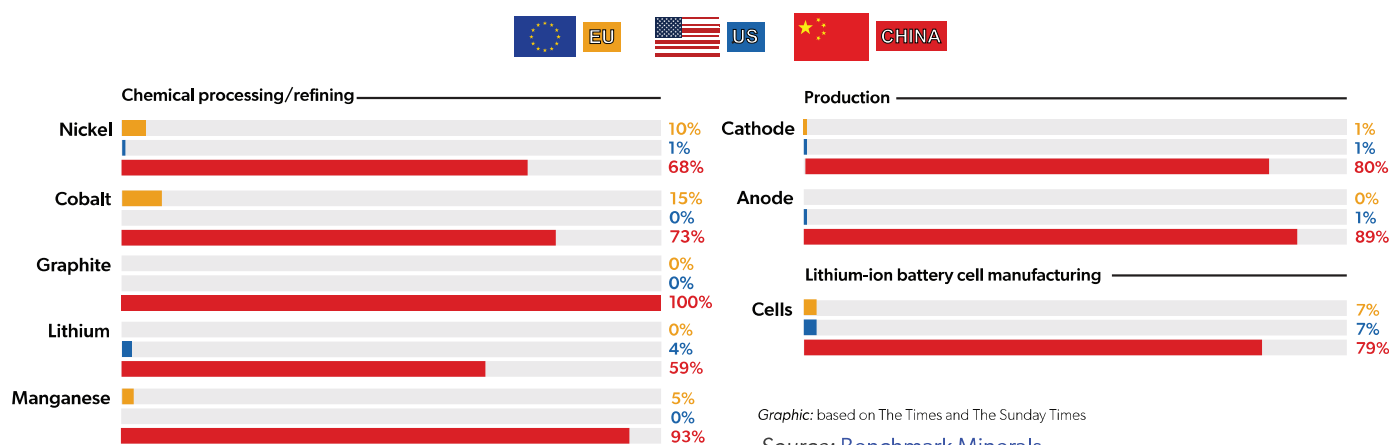
That results in massive numbers—about 4.5 million metric tons of aluminum, 1.5 million metric tons of copper, 800,000 metric tons of lithium, 400,000 metric tons of nickel, 300,000 metric tons of zinc, 200,000 metric tons of silicon, 60,000 metric tons of cobalt, and 3,000 metric tons of the rare earths metals neodymium, dysprosium, and praseodymium, which is an increase between 700 and 2,600 percent from current levels.

The report indicates that Europe faces critical shortfalls in the next 15 years without more mined and refined metals supplying its renewable energy system. Because of its rapidly rising energy costs, Europe is currently closing aluminum smelting and other industrial processing just as their governments are pressing for additional renewable energy sources and electrification.

China dominates the United States and Europe regarding critical minerals and will likely continue to do so for the foreseeable future. In 2019, the United Nations Environment Program, UNEP, reported in its "Global Trends in Renewable Energy Investment" that China has outspent every nation when it comes to green research and development. China spent nearly \$760 billion between 2010 and 2019 on renewable energy, a figure that's double the \$356 billion investment made by the United States, and which surpassed the \$698 billion invested by Europe.⁴¹ As a result, China has positioned itself to be the primary supplier of the "clean" economy, as the graph below depicts.

The United States will be competing with Europe for these critical mineral supplies, unless something is done about mining regulations in the U.S.

China dominates the processing key minerals



39 Reuters, Miner BHP may reconsider investments in Chile if tax hikes go forward, July 17, 2022, <https://finance.yahoo.com/news/miner-bhp-may-reconsider-investments-143212986.html>

40 Mining, Europe's Green Deal requires massive amounts of battery metals—study, May 1, 2022, <https://www.mining.com/europes-green-deal-requires-massive-amounts-of-battery-metals-study/>

41 Mining, Europe's Green Deal requires massive amounts of battery metals—study, May 1, 2022, <https://www.mining.com/europes-green-deal-requires-massive-amounts-of-battery-metals-study/>

CHINA'S DOMINANCE OF THE SOLAR PANEL MARKET

U.S. solar developers are highly dependent on China for materials that are instrumental in solar panel production. Whether it be the solar panels themselves, the glass that is needed for bifacial panels, or the polysilicon for the solar cells there are issues dealing with cost, delays, and human rights. Costly disruptions to the solar supply chain are emerging at a time when President Biden is planning on using solar and wind power to meet a mandate of net zero emissions from the generating sector by 2035 and the deployment of 500 million solar panels within 5 years that he touted as a candidate for president.⁴²

A critical material needed in solar panel production is polysilicon. Raw polycrystalline silicon,⁴³ commonly known as polysilicon, is a primary feedstock material used to produce solar cells. Polysilicon feedstock generally consists of large rods which are broken into chunks or chips of various sizes, then cast into multicrystalline ingots. The ingot materials are subsequently sliced into silicon wafers suitable for solar cell production.

China dominates all stages of the solar supply chain, producing between 60 and 80 percent of the world's polysilicon, wafers, crystalline silicon cells, and solar modules.⁴⁴ The United States relies almost entirely on Chinese manufacturers for low-cost solar modules, many of which are imported from Chinese-owned factories in Vietnam, Malaysia, and Thailand.⁴⁵ China supplies more than 80 percent of the world's polysilicon,⁴⁶ of which nearly half comes from Xinjiang, where the Chinese government has mass detentions of minority groups such as Uyghurs and other Muslim minorities.⁴⁷ Another 35 percent comes from other regions in China.⁴⁸ In 2019, less than 5 percent of the world's polysilicon came from U.S.-owned companies.⁴⁹

China's low-cost, coal-fired electricity has provided the country's solar-panel manufacturers a competitive advantage, allowing them to dominate global markets. Coal-fired electricity rates in the Xinjiang region can be as low as 0.22 yuan (\$0.03) per kilowatt-hour, compared with 0.6 to 0.7 yuan in central China.⁵⁰ Polysilicon factories refine silicon metal using a process that consumes large amounts of electricity, making access to inexpensive coal power a cost advantage. To support polysilicon manufacturers, China built coal-burning power plants in Xinjiang and Inner Mongolia. Since electricity is 40 percent of the operating cost of manufacturing polysilicon,⁵¹ cheap coal-fired electricity is a goal of its producers. China's cheaper polysilicon production has forced the shutdown of several factories in other countries that use power sources with lower carbon emissions than Chinese producers but with much higher electricity prices.



42 PV Magazine, Biden-Sanders task force calls for 500m solar panels in five years, July 13, 2020, <https://www.pv-magazine.com/2020/07/13/biden-sanders-task-force-calls-for-500m-solar-panels-in-five-years/>

43 Targray, Polysilicon for Solar PV Manufacturing, <https://www.targray.com/solar/solar-silicon/virgin-polysilicon?nowprocket=1#:~:text=Raw%20polycrystalline%20silicon%2C%20commonly%20referred,production%20of%20solar%20cells%20today.>

44 New York Times, President Biden extends solar tariffs, with major caveats, February 24, 2022, <https://www.nytimes.com/2022/02/04/business/economy/solar-tariffs-caveats.html?searchResultPosition=1>

45 CSIS, Solar PV Trade and Manufacturing, February 2021, <https://csis-website-prod.s3.amazonaws.com/s3fs-public/Solar%20PV%20Case%20Study%20-%20BloombergNEF.pdf?wDUUIXhfxWtA0ILU66HdshX539MvZHDI>

46 New York Times, China's Solar Dominance Presents Biden with an Ugly Dilemma, June 24, 2021, <https://www.nytimes.com/2021/04/20/business/economy/china-biden-solar-panels.html>

47 New York Times, 'Absolutely No Mercy': Leaked Files Expose How China Organized Mass Detentions of Muslims, November 16, 2019, <https://www.nytimes.com/interactive/2019/11/16/world/asia/china-xinjiang-documents.html>

48 New York Times, China's Solar Dominance Presents Biden with an Ugly Dilemma, June 24, 2021, <https://www.nytimes.com/2021/04/20/business/economy/china-biden-solar-panels.html>

49 CSIS, Solar PV Trade and Manufacturing, February 2021, <https://csis-website-prod.s3.amazonaws.com/s3fs-public/Solar%20PV%20Case%20Study%20-%20BloombergNEF.pdf?wDUUIXhfxWtA0ILU66HdshX539MvZHDI>

50 Bloomberg, Why It's So Hard for the Solar Industry to Quit Xinjiang, February 10, 2021, <https://www.bloomberg.com/news/articles/2021-02-10/why-it-s-so-hard-for-the-solar-industry-to-quit-xinjiang>

51 Bloomberg, Secrecy and Abuse Claims Haunt China's Solar Factories in Xinjiang, April 13, 2021, <https://www.bloomberg.com/graphics/2021-xinjiang-solar/>

China has become dominant in the solar manufacturing industry due to its cheap coal, lax environmental standards, government subsidies, and forced labor. Because renewable energy sources, such as wind and solar power, are intermittent and unstable, China's officials indicate that they must rely on a stable power source.⁵² They note that coal is readily available, while renewable energy needs to develop further in China despite its dominance in the solar manufacturing arena. China uses coal to make solar panels that it sells to the West, where governments direct and mandate their purchase.

In the Special Report on Solar PV Global Supply Chains,⁵³ the International Energy Agency warns of the solar PV supply imbalance. China's share in all the key manufacturing stages of solar panels currently exceeds 80 percent and for key elements, including polysilicon and wafers, it is set to increase to more than 95 percent in the coming years based on current manufacturing capacity under construction. This is more than double China's share of global PV demand. For perspective, OPEC's 13 countries produce close to 40 percent of total world oil.⁵⁴ That is, China accounts for twice as high a percentage of the world's solar panels as the world depends upon OPEC for oil. In addition, the country is home to the world's 10 top suppliers of solar PV manufacturing equipment. The agency stipulates, "This level of concentration in any global supply chain would represent a considerable vulnerability."

Since 2011, China has invested over \$50 billion in new PV supply capacity—ten times more than Europe—and created more than 300,000 manufacturing jobs across the solar PV value chain. In 2021, the value of China's solar PV exports was over \$30 billion, almost 7 percent of China's trade surplus over the last five years. In addition, Chinese investments in Malaysia and Vietnam made these countries major exporters of PV products, accounting for around 10 percent and 5 percent, respectively, of their trade surpluses since 2017. The total value of global PV-related trade—including polysilicon, wafers, cells, and modules—exceeded \$40 billion in 2021, an increase of over 70 percent from 2020.

According to the IEA, meeting international energy and climate goals requires the global deployment of solar PV to grow on an unprecedented scale, which demands a major additional expansion in manufacturing capacity, raising concerns about the world's ability to rapidly develop resilient supply chains. Annual additions of solar PV capacity around the world need to more than quadruple to 630 gigawatts by 2030 to be on track with the IEA's pathway to reach net zero emissions by 2050. Global production capacity for the key building blocks of solar panels—polysilicon ingots, wafers, cells, and modules—would need to more than double by 2030 from today's levels, and existing production facilities would need to be modernized.

High commodity prices and supply chain bottlenecks have led to an increase of around 20 percent in solar panel prices. These bottlenecks—particularly apparent in the market for polysilicon—have resulted in delays in solar PV deliveries across the globe and higher prices. Because PV production is largely concentrated in the provinces of Xinjiang and Jiangsu, where coal accounts for more than 75 percent of the annual power supply and benefits from favorable government tariffs, coal generates over 60 percent of the electricity used for global solar PV manufacturing—nearly twice its share of global power generation. Ironically, China's solar PV manufacturing industry owes its success to cheap coal-fired generation.

The IEA report finds that new solar PV manufacturing facilities along the global supply chain could attract \$120 billion worth of investment by 2030. According to the report, the solar PV sector has the potential to double the number of direct PV manufacturing jobs to about one million by 2030, with the most job-intensive areas in the manufacturing of modules and cells.

The IEA stresses that governments need to address the level of geographical concentration in global supply chains immediately if they intend to

China's share in all the key manufacturing stages of solar panels currently exceeds 80 percent and for key elements, including polysilicon and wafers, it is set to increase to more than 95 percent in the coming years based on current manufacturing capacity under construction.

52 CNBC, China Has 'No Other Choice' But to Rely on Coal Power for Now, Official Says, April 29, 2021, <https://www.cnbc.com/2021/04/29/climate-china-has-no-other-choice-but-to-rely-on-coal-power-for-now.html>

53 International Energy Agency, Solar PV Global Supply Chains, July 2022, <https://www.iea.org/reports/solar-pv-global-supply-chains>

54 Council on Foreign Relations, OPEC in a Changing World, March 9, 2022, https://www.cfr.org/backgrounders/opec-changingworld?gclid=EAlaIqobChMlxczZ_Yzp-AIVrsqUCR1kMgCIEAAAYiAAEgK6lvD_BwE

meet their net zero goals. China has been and will continue to be the leader in solar PV panels, particularly as President Biden takes cues from environmentalists to block critical mineral mines in the United States.⁵⁵ The United States is way behind and slipping further as President Biden continues to implement his “no action” policies for renewable energy supply chains.

CRITICAL MINERAL PRICES ARE SKYROCKETING

Increased demand and constrained supply are causing energy transition minerals to dramatically increase. Nickel, lithium, copper, and other minerals' prices are rising, and there isn't a new supply readily available to balance supply and keep prices lower. Likely due to concerns about Environmental, Social, and Corporate Governance (ESG), a term that refers to investments made in adherence to a set of rules about environmental and social impacts, companies have been spending less on mining expansions.

Nickel prices have skyrocketed since Russia's February 2022 invasion of Ukraine amid fears that Russian nickel supplies may be cut off. Nickel prices surged in March 2022, after which trading was temporarily suspended for several days, and new trading restrictions were applied. As a result of the high prices and the suspension of trading, automakers and other companies that need nickel, as well as other battery raw materials like lithium or cobalt, are looking for alternatives to shield against future price shocks. There are known nickel deposits in Canada and the United States in Minnesota. However, President Biden's Department of the Interior revoked existing federal leases for Twin Metals Minnesota to mine copper, nickel, cobalt, and platinum-group elements.⁵⁶ Other mines are facing similar problems.

Establishing new mining operations here or elsewhere will take years, even decades, because of the time needed to develop the infrastructure, acquire permits, and secure financing. Automakers and other big nickel buyers are looking for alternative suppliers, using more recycled material, or switching to battery designs that require less nickel. In the meantime, consumers will have to pay higher prices for goods that require nickel, including goods made from stainless steel. The nickel price increases in March 2022 would more than double the cost of the 80 pounds of nickel that an average electric car battery needs to \$1,750 per car.⁵⁷

Analysts expect nickel prices to come down to around \$25,000 a metric ton compared to the peak of \$100,000 a metric ton, and remain much higher than in 2021.⁵⁸ The price of nickel topped \$20,000 a metric ton after hovering between \$10,000 and \$15,000 a metric ton for much of the past five years because of limited production due to the pandemic. After Russia invaded Ukraine in late February 2022, the price rose above \$30,000 in a little over a week.⁵⁹ One month later, Tsingshan Holding Group of China made a bet that the price of nickel would drop. When the price rose, Tsingshan owed billions of dollars. The price then shot up to a little over \$100,000 a metric ton,⁶⁰ threatening the existence of many other companies that had bet wrong and prompting the London Metal Exchange to halt trading. By January 2023, its price was hovering around \$25,000 to \$30,000 a metric ton.⁶¹

The commodity with even greater price increases is lithium. Lithium carbonate in China jumped about 472 percent from a low in June of 2021 to a record high on March 15, 2022, according to Asian Metal Inc.⁶² An index of global lithium prices compiled by Benchmark Mineral Intelligence

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55 Institute for Energy Research, Biden Invokes Defense Production Act to Boost Domestic Critical Minerals Production, April 6, 2022, <https://www.instituteforenergyresearch.org/renewable/bidens-invokes-defense-production-act-to-boost-domestic-critical-minerals-production/>

56 Institute for Energy Research, Interior Department Revokes Federal Leases for Twin Metals Minnesota, January 27, 2022, <https://www.instituteforenergyresearch.org/regulation/interior-department-revokes-federal-leases-for-twin-metals-minnesota/>

57 New York Times, How the War in Ukraine Could Slow the Sales of Electric Cars, March 18, 2022, <https://www.nytimes.com/2022/03/18/business/energy-environment/nickel-russia-battery-electric-cars.html>

58 Ibid.

59 Ibid.

60 Ibid.

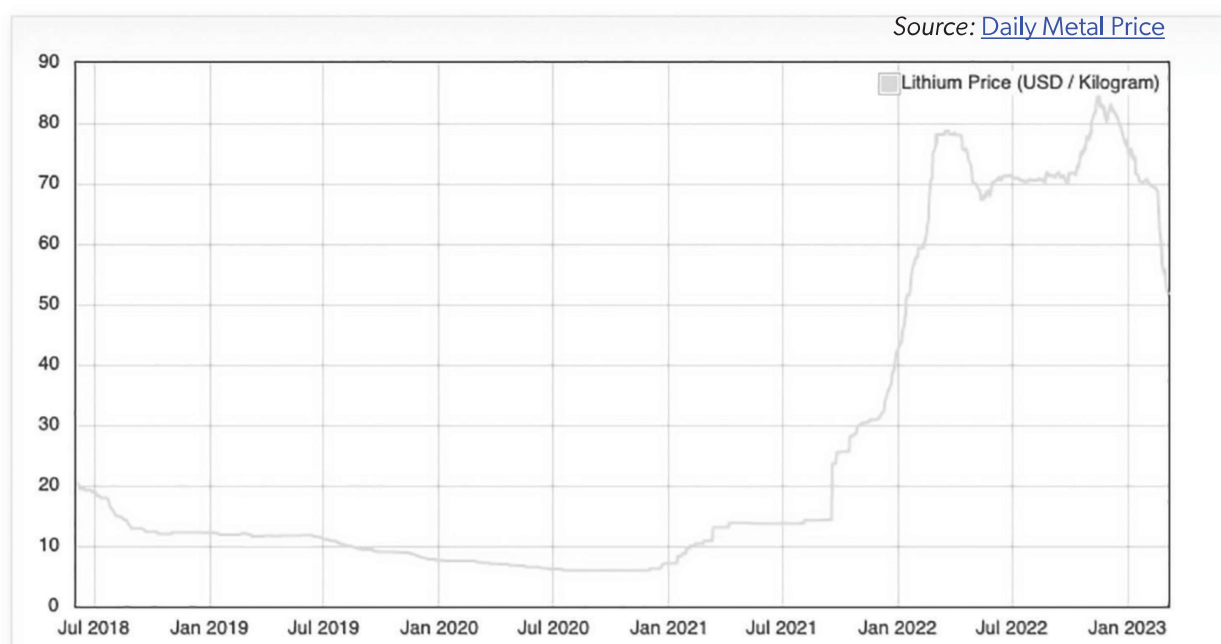
61 Daily Metal Price, <https://www.dailymetalprice.com/metalpricecharts.php?c=li&u=kg&d=240>

62 Republic of Mining, The Battery Metal Really Worrying China Is Lithium, Not Nickel, April 4, 2022, <https://republicofmining.com/2022/04/04/the-battery-metal-really-worrying-china-is-lithium-not-nickel-by-annie-lee-bloomberg-news-april-2022/>

surged almost 490 percent in the past year. Part of the reason for the price increase is that extracting lithium is a cumbersome process. In April 2022, Tesla CEO Elon Musk noted that the price of lithium had gone to “insane levels.”⁶³ In 2022, lithium prices reached over \$80 per kilogram.⁶⁴ By the middle of March 2023, however, lithium prices eroded to just under \$45 per kilogram—still over 4 times higher than in 2020—mostly because demand for the metal has not risen as fast as some in the industry expected.

LITHIUM PRICE (USD/KILOGRAM)

Lithium Prices for the Last 5 Years



A new reality for President Biden’s net zero ambition is that mining companies are not increasing the level of spending that would be needed to meet his and other western countries’ goals. Similar to the oil industry, mining companies are responding to pressure from investors to give priority to dividends and share buybacks and to limit the sector’s environmental damage, rather than invest in new mines.

Lithium use is exploding due to the growth in electric vehicles and its use in multiple technology industries, including cell phones and mobile computers. Lithium has also become the preferred metal along with other elements including cobalt for batteries. China has largely cornered the market on lithium production due to its own production and its stake in other countries. Other large lithium mines are located in South America and Australia. The United States has 3 percent of the world’s lithium reserves, but produces very little of the world’s supply.

Joe Lowry, an expert known in mining circles as “Mr. Lithium,” has been sounding the alarm on the prospects of a lithium shortage. Since 2012, Lowry has been a consultant to mining companies and an investor, owning shares of companies including Tesla and Lithium Americas. According to Lowry, in the next two years, even

63 Fox Business, Lithium shortages impact Tesla, other EV carmakers, numerous tech markets, April 25, 2022, <https://www.foxbusiness.com/markets/lithium-shortages-tesla-ev-tech-markets>

64 Daily Metal Price, <https://www.dailymetalprice.com/metalpricecharts.php?c=li&u=kg&d=240>

though there will be significant growth in lithium supply, it will be less than demand, so the gap will continue to grow. While there will be a day in the future when lithium is in oversupply, it won't be in this decade. A battery factory can be built in two years, but it takes up to a decade to bring on a lithium project.⁶⁵

A new reality for President Biden's net zero ambition is that mining companies are not increasing the level of spending that would be needed to meet his and other western countries' goals. Similar to the oil industry, mining companies are responding to pressure from investors to give priority to dividends and share buybacks and to limit the sector's environmental damage, rather than invest in new mines.⁶⁶ Project spending by 10 large mining companies, including Rio Tinto PLC, BHP Group Ltd., and Glencore PLC, is expected to stay at roughly \$40 billion in 2023, putting capital expenditures well below a peak in 2012 close to \$80 billion.⁶⁷ With rising costs for fuel and equipment, higher interest rates, and challenges developing deposits in emerging markets that are seeking a greater share of industry earnings, it is no wonder that many mining companies are being cautious about investing in new mines and infrastructure.⁶⁸

Total global mining capital expenditures, which include smaller firms and state-owned enterprises, averaged about \$100 billion annually over the past decade. But mining companies need to spend \$160 billion annually to accelerate an energy transition away from hydrocarbons to meet the timelines that politicians want. The low expenditures were the result of a recent rally in copper and iron ore, with both materials up more than 40 percent in the past two years, driving up costs for solar panels, wind turbines, and batteries.⁶⁹

A FURTHER NOTE ON CHINA

China has the willingness and capability to pursue development of the necessary energy and minerals to retain its global dominance. China's "Silk Belt and Road" initiative links and further strengthens trade relations with other nations, most notably for their natural resource wealth.⁷⁰ Linking to developing countries by both surface roads and maritime infrastructure, China's initiative extends credit to nations with little economic base who are rich in natural resources that China wishes to develop for future manufacturing, economic, and national security interests. China offers infrastructure investments these nations require, in return for commitments of natural resources in payment.

China's commitment and capabilities to develop the massive infrastructure necessary for economic growth is clear. For example, during just 3 years of the Obama administration, China used 140 percent of the cement used by the United States during the entire 20th century.⁷¹ China makes over half the world's steel and uses over half the world's coal,⁷² almost nine times that of the United States.⁷³ Clearly, China has the means and—more importantly—the will, to develop these resources and thus spread its influence throughout the globe.

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65 Mining, 'Mr. Lithium' warns there's not enough battery metal to go around, April 22, 2022, <https://www.mining.com/web/mr-lithium-warns-theres-not-enough-battery-metal-to-go-around/#:~:text=Lithium%20warns%20there's%20not%20enough%20battery%20metal%20to%20go%20around,->

66 Wall Street Journal, Commodity Prices Have Soared, but Miners Aren't Investing, May 25, 2021, https://www.wsj.com/articles/commodity-prices-have-soared-but-miners-arent-investing-11621940401?mod=article_inline

67 Wall Street Journal, Mining Firms Cautious Spending Threatens Shift to Green Energy, June 19, 2022. https://www.wsj.com/articles/mining-firms-cautious-spending-threatens-shift-to-green-energy-11655566976?st=qewjwqyp6d3iijh&reflink=desktopwebshare_permalink

68 Wall Street Journal, Governments Want to Cash in on Miners' Ballooning Profits, July 12, 2021, https://www.wsj.com/articles/governments-want-to-cash-in-on-miners-ballooning-profits-11626028199?mod=article_inline

69 Wall Street Journal, Inflation Adds to Cost of Clean Energy Transition, December 19, 2021, https://www.wsj.com/articles/inflation-adds-to-cost-of-clean-energy-transition-11639918803?mod=article_inline

70 Council on Foreign Relations, China's Massive Belt and Road Initiative, January 28, 2020, <https://www.cfr.org/background/chinas-massive-belt-and-road-initiative>

71 Washington Post, How China used more cement in 3 years than the U.S. did in the entire 20th century, March 24, 2015, <https://www.washingtonpost.com/news/wonk/wp/2015/03/24/how-china-used-more-cement-in-3-years-than-the-u-s-did-in-the-entire-20th-century/>

72 Foreign Policy, Don't Let China Steal Your Steel Industry, May 19, 2020, <https://foreignpolicy.com/2020/05/19/dont-let-china-steal-your-steel-industry/>

73 BP Statistical Review of World Energy, July 8, 2021, <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html>

Further, to meet the Biden administration's goals, substantially more critical minerals will be needed. While the United States is largely dependent on imports currently, it could secure some of these resources by opening mines that are currently having trouble receiving final government approvals. Without increasing the U.S. extraction and processing of these critical minerals, the United States will become more dependent on China for them as China dominates their supply chains. This makes the U.S. much more dependent on China than it ever was on the Middle East for oil. The U.S. imports about 80 percent of its rare earth requirements from China, compared to a high of 23 percent of imported oil from the Middle East in 2001.⁷⁴

China thus sees efforts among western nations, including the United States and Europe, to pursue a "green transition" as a boon to their economy since they are the predominant force in the world in the markets for the materials and minerals necessary for it. As mentioned, they control significantly more of the world's supply of minerals than any nation or group of nations ever controlled the world's oil supplies.

74 Oil Price, How the United States has Reduced Its Dependence on Middle East Oil, January 15, 2020, <https://oilprice.com/Energy/Energy-General/How-The-US-Has-Reduced-Its-Dependence-On-Middle-East-Oil.html>

MINE, BABY, MINE: THE U.S. CAN INCREASE OUR MINING CAPACITY

The situation with energy and materials for massive increases in renewable energy and EVs looks bleak. However, the not-too-distant past gives us a good example of how new technologies, coupled with a reasonable regulatory environment, have overcome natural resources constraints here in the United States.

Oil and natural gas production in the mid-2000s looked like they were in terminal decline, and federal officials believed that the future of oil and natural gas development in the United States was limited. In 2006, President Bush declared that America was “addicted to oil,” and created the renewable fuel standard mandating the use of billions of gallons of biofuels and cellulosic ethanol. President Obama, as late as 2012, said that drilling for more oil as a response to high energy prices was essentially stupid. Specifically, he said, “I mean, the American people aren’t stupid. They know that’s not a plan—especially since we’re already drilling. That’s a bumper sticker. It’s not a strategy to solve our energy challenge.”⁷⁵

As we know today, President Obama was completely wrong. From February 2012 and March 2020, oil production in the United States grew 105 percent and the price of gasoline fell from \$3.26 per gallon to \$2.53 per gallon.⁷⁶

DRILL, BABY, DRILL WORKED

How did the United States prove both President Bush and President Obama wrong on the potential for oil and natural gas development? The answer was new technology, reasonable regulation, and private ownership of resources.

Starting in the 1970s, the Department of Energy (DOE) and the private sector started working together to attempt to extract hydrocarbon resources from shale formations.⁷⁷ The DOE spent millions of dollars to develop various technologies to improve hydraulic fracturing. But advancing the technology was not enough to make these new drilling and fracturing technologies a cost-effective reality. That required something else, which came from the private sector.

The next critical step was real-world experimentation and the regulatory environment played an important role in making this natural gas revolution happen. Entrepreneurs experimented to figure out how to make these drilling and fracturing technologies work in a cost-effective manner.

This experimentation mostly occurred on state and private land and not nearly as much on federal lands. The major difference was—once again—the regulatory environment. One illustrative example of the difference in the regulatory environment is the amount of time necessary to obtain a permit to drill. On federal lands in 2012 it took an average of 307 days to obtain a permit to drill, but only 10 days in North Dakota, 14 days in Ohio, and 27 days in Colorado. The regulatory and permitting morass on federal lands made the necessary experimentation difficult on federal lands.



Marcellus-Shale gas drilling well in Southwestern Pennsylvania.

75 President Barack Obama, Obama: ‘The American People Aren’t Stupid’, Feb. 23, 2012, speech at the University of Miami, <https://www.youtube.com/watch?v=wyFX2iM-dSE&ab>

76 Energy Information Administration, U.S. Field Production of Crude Oil, <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=p&s=mcrfpus2&f=m>; Energy Information Administration, U.S. All Grades All Formulations Retail Gasoline Prices (Dollars per Gallon), https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=P&s=EMM_EPMO_PTE_NUS_DPG&f=M

77 Breakthrough Institute, <https://thebreakthrough.org/issues/energy/where-the-shale-gas-revolution-came-from>

The shale revolution was helped along by federal funding to advance technology but hindered by federal regulations on federal lands. As a result, the shale revolution gathered speed almost exclusively on private and state lands in places like Pennsylvania, Texas, North Dakota, Ohio, and Colorado.

WHAT DOES THIS MEAN FOR MINERALS AND MATERIALS?

Is it possible to recreate the oil and gas revolution with minerals and materials? We believe so. The United States provides a good operating environment for mining companies once they are actually operating because of the rule of law and the unlikelihood of the government nationalizing the mines. In much the same way as patents protect intellectual property, private property and its Constitutional protections promote investment and technologies that reward those willing to risk. That said, it is incredibly difficult to permit new mines in the United States, despite enormous geological potential.

If the Biden administration or others are serious about net zero goals not wrecking the economy, then it is critically important that they support the reforms necessary to enable a large increase in new mines and mineral processing in the U.S. With the right regulatory environment, we could see a mining renaissance like the dramatic growth in oil and gas production over the past 15 years, with all of its economic, national security, and geopolitical benefits.

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THE U.S. IS CURRENTLY MOVING IN THE WRONG DIRECTION ON MINING

As this report shows, there will be strong demand for many minerals as EVs continue to enter the market and other energy technologies emerge. The Biden administration has aggressive net zero goals which would greatly increase the demand for these minerals. At the same time, it has been working against allowing the needed new mines in the United States. It is illogical to develop technology that relies heavily on increased mining, while refusing to take any action to develop the capacity for that mining, and choosing instead to block or slow that development wherever possible.

In May 2021, President Biden indicated that he wants to import critical metals, supposedly from allies.⁷⁸ However, our European allies are actually temporarily closing mining and processing facilities due to their exceptionally high energy prices and reducing exports to fill the need for critical mineral resources for their own energy transition. As discussed in the previous section, a majority of global lithium production comes from China, Australia, Argentina, and Chile. Russia dominates the global nickel market, and the Democratic Republic of Congo is the world's largest cobalt producer (with half of its large mines owned by China). Child labor is being used to mine cobalt in the Congo and forced labor from Uyghurs and other Muslim minorities is being used in China. As a response to these realities, President Biden released an executive order regarding the domestic mining of these critical minerals.

President Biden talks about wanting domestic production of these minerals, but his actions demonstrate otherwise. His administration has focused on making it more difficult to mine in the United States.

On March 31, 2022, President Biden invoked the Korean War era Defense Production Act (DPA) to attempt to increase domestic production of minerals used in making electric vehicles, such as nickel, lithium, and cobalt, because the country is depending on unreliable foreign sources for many materials necessary for transitioning to the use of renewable energy.⁷⁹ The act allows Defense Department (DOD) funding for some early-stage mine development activities. President Biden's order directs the DOD to consider at least five metals—lithium, cobalt, graphite, nickel, and manganese—as essential to national security and authorizes steps to bolster domestic supplies. But President Biden's action does little to increase domestic mining because he did not waive, streamline, or suspend existing regulations. He also failed to address a major hurdle to increased domestic extraction of these critical minerals: the multiple years-long process needed to obtain the necessary federal permits for a new mine.

President Biden talks about wanting domestic production of these minerals, but his actions demonstrate otherwise. His administration has focused on making it more difficult to mine in the United States. It has revoked federal leases; used regulatory action to delay or revoke mining, air pollution, and water quality permits; and labeled a flowering plant “endangered” as ways to delay or cancel metal mines in the United States. Further, a study by finance company MSCI estimates that the majority of U.S. reserves for cobalt, lithium, and nickel are located within 35 miles of Native American reservations, causing a potential conflict with President Biden's stated commitment to racial equity.⁸⁰

In April 2022, the Department of Interior (DOI) reversed a Trump administration decision that limited the scope of compensatory mitigation the Department could force upon projects on federal land as a condition of receiving a permit. This will hit mining projects especially hard.⁸¹ Under

78 FrontPage Magazine, Biden Lied to Miners: “Made in America” Electric Car Metals Will Be Imported, May 25, 2021, <https://www.frontpagemag.com/point/2021/05/biden-lied-miners-made-america-electric-car-metals-daniel-greenfield/>

79 AP News, Biden order to boost mining may not have quick payoff, April 30, 2022, <https://apnews.com/article/biden-technology-business-trending-news-environment-04e20d148dc50c09831d2530d1fd2f8e>; New York Times, Biden Invokes Cold War Statute to Boost Critical Minerals Supply, March 31, 2022, https://www.nytimes.com/2022/03/31/business/economy/biden-minerals-defense-production-act.html?campaign_id=4&emc=edit_dk_20220401&instance_id=57307&nl=dealbook®i_id=63692790&segment_id=87196&te=1&user_id=edd9a99552656979b642d62e6445e311

80 MSCI, Mining Energy-Transition Metals: National Aims, Local Conflicts, June 3, 2021, <https://www.msci.com/www/blog-posts/mining-energy-transition-metals/02531033947>

81 United States Department of the Interior, Memorandum, Withdrawal of M-37046 and Reinstatement of M-37039, “The Bureau of Land Management’s Authority to Address Impacts of its Land Use Authorizations Through Mitigation”, April 15, 2022, <https://www.doi.gov/sites/doi.gov/files/m-37075-compensatory-mitigation-m-op-reinstatement-04.15.22.pdf>

the new guidance, opponents in the federal government could assess mitigation located far from the project, giving bureaucrats a blank check to request whatever they wish of a permit seeker with little controls or relationship to the project. This decision was made less than a week after the DOI Inspector General reported that there were no controls or apparent records justifying previous versions of this program and warned they may have to review the overall program again.⁸²

The following details a few of the critical mineral mines in the United States seeking to obtain permits so that they can begin mining operations, and the obstacles they face from the federal government and environmentalists in doing so.

TWIN METALS MINE

In January 2022, the Biden administration revoked the federal leases for the Twin Metals mine in Minnesota that contains copper, nickel, cobalt, and platinum-group elements.⁸³ In January 2023, the Biden administration followed that decision by withdrawing more than 225,000 acres of the Superior National Forest from consideration for mining operations for 20 years, thereby ensuring the Twin Metals project's demise for the foreseeable future.⁸⁴ The two leases for the Twin Metals mine originated in 1966 and were up for renewal in 2016. In December 2016, however, the Obama administration declined to renew the two leases after a legal opinion from the Interior Department held that Twin Metals did not have an automatic right to renew the leases.⁸⁵ The following year, the Trump administration reversed that decision, and the Bureau of Land Management (BLM) subsequently reinstated the leases and then renewed them for an additional ten years.⁸⁶ With those leases, Twin Metals formally proposed its mining plans in 2019, which began a multi-year environmental review and permitting process by state and federal regulators.⁸⁷ But, in January 2022, a new legal opinion was released by the Biden administration that overturned the Trump administration's actions, revoking the leases.⁸⁸ The final straw was the withdrawal of the acreage from the Superior National Forest for two decades. Twin Metals is expected to challenge these decisions and defend its existing mineral rights.

Since 2010, the Twin Metals mine has invested more than \$450 million into the Minnesota economy.⁸⁹ The Twin Metals project, once operational, is projected to directly employ 750 people long-term⁹⁰. Furthermore, approximately two spinoff jobs would be created in other industries for each mining job. These spinoff jobs provide new employment opportunities in manufacturing, retail, restaurants, and energy. The Twin Metals project is expected to generate more than 1,500 indirect and induced jobs in goods and services and other sectors, while providing essential minerals for the burgeoning demand expected from President Biden's net zero ambitions.



Processing plant at Galaxy Lithium Mine in Ravensthorpe, Western Australia. Mechanical processing used to refine lithium spodumene concentrate.

82 United States Department of the Interior, Weaknesses in the BLM's Compensatory Mitigation Program Data Management, April, 2022, <https://www.oversight.gov/sites/default/files/oig-reports/DOI/AuditBLM-CompensatoryMitigationProgramDataMgmt.pdf>

83 Institute for Energy Research, Interior Department Revokes Federal Leases for Twin Metals Minnesota, January 27, 2022, <https://www.instituteforenergyresearch.org/regulation/interior-department-revokes-federal-leases-for-twin-metals-minnesota/>

84 The Federalist, Interior Department Blocks Minnesota Twin Metals Mining Project In Big Win For Beijing, January 26, 2023, <https://thefederalist.com/2023/01/26/interior-department-blocks-minnesota-twin-metals-mining-project-in-big-win-for-beijing/>

85 MPR News, Feds halt Twin Metals plan for Minn. Copper mine near Boundary Waters, December 15, 2016, <https://www.mprnews.org/story/2016/12/15/feds-deny-minerals-lease-renewals-for-twin-metals-mine>

86 MPR News, Feds reverse course, keep Minnesota copper mine alive, December 22, 2017, <https://www.mprnews.org/story/2017/12/22/twin-metals-mn-copper-mine-alive-fed>; MPR News, Interior Department renews leases for Minnesota mine project, May 2, 2018, <https://www.mprnews.org/story/2018/05/02/interior-department-renews-leases-for-minnesota-mine-project>; MPR News, Trump administration gives Twin Metals new lease on copper-nickel mining, December 20, 2018, <https://www.mprnews.org/story/2018/12/20/feds-move-to-formally-renew-leases-for-twin-metals-mine>

87 MPR News, Twin Metals submits formal plans for mine near the boundary water, December 18, 2019, <https://www.mprnews.org/story/2018/12/20/feds-move-to-formally-renew-leases-for-twin-metals-mine>

88 United States Department of the Interior, Authority to Cancel Improperly Renewed Twin Metals Mineral Leases and Withdrawal of M-37049, "Reversal of M-37036, 'Twin Metals Minnesota Application to Renew Preference Right Leases (MNES-01352 and MNES01353)'" , January 25, 2022, <https://www.doi.gov/sites/doi.gov/files/m-37072.pdf>

89 Jobs for Minnesotans, Jobs & Impact, <http://jobsforminnesotans.org/jobs/>

90 Ibid.

On May 24, 2022, Congressional Democrats held a hearing on legislation that would permanently ban mining in the Superior National Forest. That was followed by the U.S. Forest Service (USFS) releasing, on June 23, 2022, an environmental assessment recommending a region-wide mining ban on minerals, including copper, nickel, cobalt, and platinum-group elements in the Superior National Forest. The Forest Service included taconite mining in that ban, which northern Minnesotans have been doing safely for the last 130 years and which accounts for 80 percent of all U.S. produced steel.⁹¹ Also, on June 23, 2022, the USFS and BLM announced that they will request public comment on the environmental assessment to withdraw lands from new mineral leasing for 20 years in the Rainy River watershed, which is adjacent to the Boundary Waters Canoe Area Wilderness in the Superior National Forest.⁹²

In August 2022, the developers sued the Biden administration to seek the reinstatement of federal mineral rights leases that are crucial to the \$1.7 billion project. Twin Metals Minnesota alleged in its lawsuit, filed in federal court in Washington, that the Interior Department acted illegally earlier this year when it canceled the leases. The company asked the court to declare that those leases remain valid and in force, so that it can proceed with the environmental review and permitting process.⁹³



Heavy dump truck carrying ore from an open-pit mining operation.

POLYMET MINE

Also in Minnesota, the PolyMet copper and nickel mine is being held up by court and regulatory action despite having undergone more than a decade of thorough, public environmental reviews.⁹⁴ The PolyMet copper and nickel mine is located within Minnesota's Mesabi Iron Range and would be the first copper-nickel open pit mine in Minnesota. Besides holding significant deposits, the project has existing rail, roads, utilities, and an established supplier network in a traditional mining area where mining has occurred for well over a century.⁹⁵ Like other projects in the region, PolyMet has a Project Labor Agreement with building trades unions who are familiar with and expert in mining projects.

The project first entered the environmental review and permitting process in 2005, when George W. Bush was president. Seventeen years later, aspects of the mine's plan and its permits are still being investigated or challenged in court due to environmentalist opposition. According to PolyMet, its mining techniques, water treatment, and waste reclamation plans meet environmental standards and will even improve water quality in the area.

In 2019, PolyMet, under the Trump administration, received all state and federal permits needed to mine for 20 years, but three key permits needed for the project were subsequently suspended or reversed.

One of those is the project's permit to mine—a permit approved by the Minnesota Department of Natural Resources (DNR) that was reversed by the Minnesota Supreme Court in April 2021.⁹⁶ PolyMet's permit to mine indicates planned mining and reclamation activities will conclude in about 2072, though long-term maintenance and "active water treatment" will continue indefinitely until state rules on mine closure are met and the need for maintenance ends. The Supreme Court indicated that PolyMet models show "post-closure maintenance" is likely needed for at least 200 years. The DNR will determine a revised date and get public input on it. The court also told DNR that it must hold a "contested case

91 Press Release, Stauber Statement Blasting Biden Administration's Latest Anti-Mining Action, June 23, 2022, <https://stauber.house.gov/media/press-releases/stauber-statement-blasting-biden-administration-s-latest-anti-mining-action>

92 Press Release, SDA Forest Service Announces Plans to Open Comments on Rainy River Mineral Withdrawal in Northern Minnesota, June 23, 2022, <https://www.usda.gov/media/press-releases/2022/06/23/usda-forest-service-announces-plans-open-comments-rainy-river>

93 CBS, Twin Metals sues Biden administration to regain mine leases near Boundary Waters, <https://www.cbsnews.com/minnesota/news/twin-metals-sues-biden-administration-to-regain-mine-leases-near-boundary-waters/>

94 MinnPost, Why 2022 could be a critical year for the controversial PolyMet mining project in northern Minnesota, January 5, 2022, <https://www.minnpost.com/greater-minnesota/2022/01/why-2022-could-be-a-critical-year-for-the-controversial-polymet-mining-project-in-northern-minnesota/>

95 Minnesota Department of Natural Resources, Minnesota mining history, <https://www.dnr.state.mn.us/education/geology/digging/history.html#:~:text=Iron%20ore%20was%20discovered%20on,ore%20out%20of%20the%20rock.>

96 State of Minnesota Supreme Court, In the Matter of the NorthMet Project Permit to Mine Application, April, 2021, <https://mn.gov/law-library-stat/archive/supct/2021/OPA181952-042821.pdf>

hearing” on whether the company’s plan to use bentonite, a clay sealant, in its tailings pond as a key pollution prevention strategy would be effective.

PolyMet opponents are also suing state regulators over a water-pollution permit granted by the Minnesota Pollution Control Agency. In June 2021, the federal Environmental Protection Agency (EPA) ruled that discharges from PolyMet may affect water quality, as required by the Clean Water Act.⁹⁷ That allowed opponents of PolyMet to object to a federal “Section 404” permit previously granted by the U.S. Army Corps of Engineers (Army Corps) and request a hearing on the issue. The 404 permit is tied to construction-related damage to wetlands including the discharge of dredged and fill material into water. The Army Corps is holding the hearing, but meanwhile, President Biden’s EPA has recommended that the permit not be reissued. That ruling by the EPA occurred after President Biden invoked the Defense Production Act, and conflicts with his statements about wanting to develop a domestic critical metals mining industry.⁹⁸

Another issue involves a critical air emissions permit given to the project.⁹⁹ The court ruled that the Minnesota Pollution Control Agency had not sufficiently justified granting the permit after opponents raised allegations that PolyMet was planning a much larger mine. A report that PolyMet filed with Canadian regulators suggested that PolyMet was considering expanding the mine to four times the size that the air permit would allow. In December, the Minnesota Center for Environmental Advocacy affirmed the permits, saying in an agency order that there was not enough evidence to prove PolyMet was asking for the smaller permit “in bad faith.”¹⁰⁰

The company expects the roughly \$1 billion project to bring 360 direct jobs to the region and more than 600 indirect ones after construction.

IONEER LTD.’S LITHIUM MINE

Ioneer Ltd.’s lithium mine in Nevada, which could supply 22,000 metric tons of lithium annually (enough for about 400,000 electric cars), is being held up by environmentalists, who claim the mine threatens Tiehm’s buckwheat, a rare flowering plant.¹⁰¹ The Trump administration’s Interior Department refuted that claim, finding that it was actually squirrels who were threatening the buckwheat. Despite the analysis, environmentalists asked the Biden administration to list the buckwheat as an endangered species. Interior regulators subsequently proposed a listing to that effect. The U.S. Fish and Wildlife Service (USFWS) will permanently zone off 910 acres near Ioneer Ltd.’s proposed lithium mine to preserve the flower, a major step backward in the project’s bid to proceed.¹⁰² The Fish and Wildlife Service indicated in its filing that the zone should “not have a significant economic impact” on nearby business activity. Ioneer believes it can protect the flower, even if it needs to tweak its mine plans.

Final approval by BLM is based on a completed environmental review under the National Environmental Policy Act (NEPA), which begins with the public review and comment phase of the NEPA process that will be incorporated in the Environmental Impact Statement (EIS) Plan. The NEPA process culminates in the BLM’s Record of Decision (ROD), which is expected in the first quarter of 2024.¹⁰³

Pouring hundreds of millions of dollars into a domestic mining industry that remains unable to obtain permits in a timely and rational manner does little to enhance U.S. energy security or facilitate the demand for secure domestic mineral supplies.

97 United States Environmental Protection Agency, PolyMet NorthMet Mine, <https://www.epa.gov/mn/polymet-northmet-mine#nextsteps>

98 MPR News, EPA recommends Army Corps not reissue PolyMet water permit, May 3, 2022, <https://www.mprnews.org/story/2022/05/03/army-corps-of-engineers-holds-hearing-on-controversial-polymet-water-permit>

99 AP News, 2nd PolyMet permit complaint reaches Minnesota Supreme Court, November 5, 2020, <https://apnews.com/article/environment-minnesota-courts-air-pollution-pollution-00a50365e8717c66eaa48aa7047149f4>

100 State of Minnesota Pollution Control Agency, In the Matter of Issuance of Air Emissions Permit No. 13700345-101 for PolyMet Mining, Inc., City of Hoyt Lakes, St. Louis County, Minnesota, December 20, 2021, <https://www.pca.state.mn.us/sites/default/files/Findings%20FactAndConclusionsOfLawDec20-2021.pdf>

101 WSJ Opinion, Critical Mineral Contradictions, April 3, 2022, https://www.wsj.com/articles/critical-mineral-green-energy-climate-change-electric-cars-biden-mining-zinc-lithium-copper-china-pollution-endangered-species-defense-production-act-11648850666?st=ileha2hnjvl5tom&reflink=desktopwebshar_permalink

102 Reuters, rare flower to get protected zone near Ioneer’s Nevada lithium mine, February 3, 2022, <https://www.reuters.com/business/environment/us-regulators-preserve-acreage-near-ioneers-lithium-mine-site-2022-02-02/>

103 PR Newswire, Ioneer’s Rhyolite Ridge Project Advances into Final Stage of Permitting, December 19, 2022, <https://www.prnewswire.com/news-releases/ioneers-rhyolite-ridge-project-advances-into-final-stage-of-permitting-301706219.html>

In normal circumstances, the process of getting a mine to first production can be a 7 to 10 year enterprise.¹⁰⁴ But recalcitrant federal bureaucracies and politics can extend that timeline, as seen by the Twin Metals mine, whose lease began in 1966. Pouring hundreds of millions of dollars into a domestic mining industry that remains unable to obtain permits in a timely and rational manner does little to enhance U.S. energy security or facilitate the demand for secure domestic mineral supplies. This, unfortunately, is the reception those interested in investing in mining in the U.S. are currently accustomed to receiving.

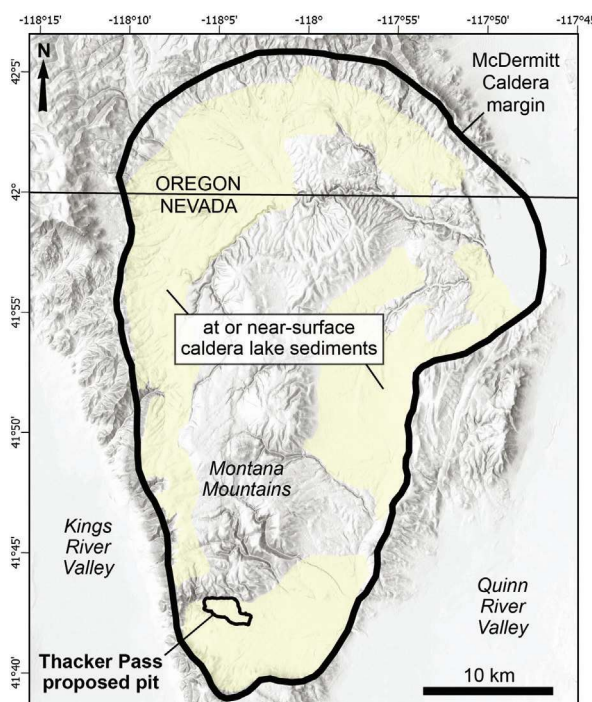
THACKER PASS LITHIUM MINE

The Thacker Pass Lithium Mine is located in Humboldt County, Nevada, about 25 miles from the Nevada-Oregon border. The proposed mine could produce a quarter of today's global lithium demand. This is significant, but demand for the mineral is skyrocketing due to electric vehicle mandates from governments here and around the world. The BLM granted the project its final federal permit in January 2021. The mine's development, however, is still on hold, due to legal challenges. On February 25, 2022, the final state-level permits (air, water, and mining) required for the proposed Thacker Pass Lithium Mine Project were issued, moving it a step closer to operation.¹⁰⁵ As part of the decision, no mining will be allowed below the water table.

A federal lawsuit was filed by a coalition of nearby indigenous communities, environmental groups, and a local rancher that argued the environmental review downplayed the likely effects on groundwater, streams, and a threatened species of trout.¹⁰⁶ The suit alleges that when the BLM approved the project in January 2021, it was based on a flawed environmental review and rushed through without adequate consultation of tribes, as required by law.¹⁰⁷ The district court ruled in favor of the BLM and Lithium Americas, allowing Lithium Americas to break ground on the project in March 2023.¹⁰⁸

In October 2022, Lithium Americas Corporation, the company developing the mine, entered a Community Benefits Agreement (CBA) with the Fort McDermitt Paiute and Shoshone Tribe, which is located approximately 40 miles from the Thacker Pass project, in Humboldt County, Nevada. The CBA establishes a framework for continued collaboration and defines the long-term benefits for the Tribe, the largest Native American community within the vicinity of the Project. The Company agreed to build an 8,000 square feet community center for the Tribe that includes a daycare, preschool, playground, cultural facility and communal greenhouse to support reclamation efforts and provide income for the Tribe.¹⁰⁹

Lithium Nevada is expecting to be fully operational in 2024, when the mine is expected to produce 60,000 tons per year of battery quality lithium carbonate over a 46-year life span. The mine will provide over 1,000 construction jobs and 300 permanent jobs. After mining, the open pits will be filled and restored with sagebrush and mine tailings will be placed in dry stacks. The mine will consume less than 1 percent of the approximately 350,000 acre-feet of water pumped annually from wells in the county.¹¹⁰



Proposed boundaries and surrounding areas of the Thacker Pass Project. Courtesy of Lithium Americas.

104 Forbes, Biden's Efforts to Boost Mining Won't Matter Without Permits, April 4, 2022, <https://www.forbes.com/sites/davidblackmon/2022/04/04/bidens-efforts-to-boost-mining-wont-matter-without-permits/?sh=257bf78c6720>

105 Nevada Division of Environmental Protection, Thacker Pass Lithium Mine, <https://ndep.nv.gov/land/thacker-pass-project>

106 Protect Thacker Pass, Native Americans Enter Legal Battle Against Thacker Pass Lithium Mine, July 26, 2021, <https://www.protectthackerpass.org/native-americans-enter-legal-battle-against-thacker-pass-lithium-mine/>

107 Grist, A controversial lithium mine in Nevada is one step closer to operation, March 2, 2022, <https://grist.org/equity/nevada-issues-permits-for-lithium-mine/>

108 Hilary Beaumont, Nevada lithium mine breaks ground despite Indigenous opposition, Al Jazeera, Mar. 15, 2023, <https://www.msn.com/en-us/news/world/nevada-lithium-mine-breaks-ground-despite-indigenous-opposition/ar-AA18EDIf>

109 Lithium Americas, <https://www.lithiumamericas.com/news/lithium-americas-signs-community-benefitsagreement-with-fort-mcdermitt-paiute-and-shoshone-tribe>

110 Washington Times, Nevada lithium mine pits Biden green agenda against radical environmentalists, June 13, 2022, <https://www.washingtontimes.com/news/2022/jun/13/nevada-lithium-mine-pits-biden-green-agenda-against/>

RESOLUTION COPPER MINE

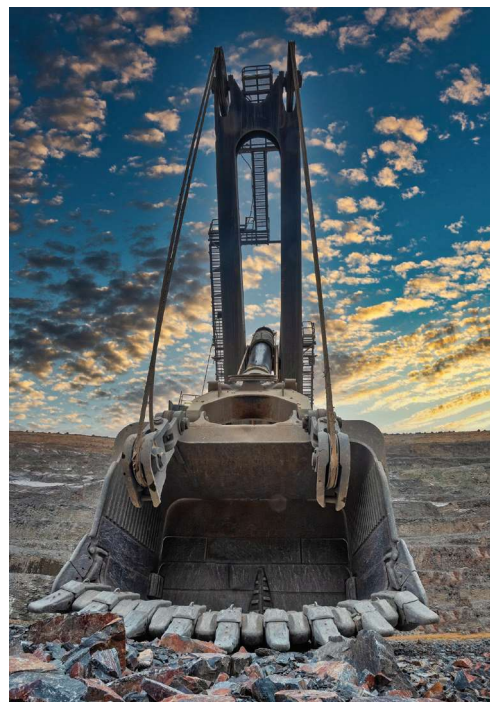
The Resolution copper mine in Oak Flat, Arizona, which can meet about 25 percent of U.S. copper demand, is currently under federal environmental review.¹¹¹ In March 2021, just weeks into the new Biden administration, the federal government rescinded its approval for the copper mine days before it was to transfer thousands of acres of federal land for the project.¹¹² The land could have been handed over under a congressionally approved swap in which the federal government would have traded 2,422 acres of land to Resolution Copper in exchange for 5,459 acres of other land in southeast Arizona.¹¹³

President Biden's Department of Agriculture (USDA) said it ordered the rescission to allow for a "thorough review based on significant input from collaborators, partners and the public" after the January 15, 2021 release of a final environmental impact statement on the project. In ordering the reversal, the USDA cited President Biden's memorandum calling for increased tribal consultation, saying it wanted to ensure "the Forest Service has complied with the environmental, cultural, and archaeological analyses required."¹¹⁴ Further, in September 2021, the Democratic controlled House Natural Resources committee voted to include language in the House reconciliation package to block the building of the Resolution copper mine. It did not pass the Senate.¹¹⁵

In November 2022, the 9th U.S. Circuit Court of Appeals indicated that they will weigh whether the federal government improperly gave Rio Tinto Plc thousands of acres in Arizona for its Resolution Copper mining project, taking into account religious rights versus the needs of the green energy transition. The San Francisco-based court said it will decide the case en banc, meaning all of its 11 members will participate in the decision.

Three members of the court previously ruled in favor of Rio and the land swap. The new hearing occurred on March 21, 2023, and a decision will be released in the coming months. The dispute centers on the federally owned Oak Flat Campground, which some Apache consider home to deities and which sits atop a reserve of more than 40 billion pounds of copper.¹¹⁶

The proposed mine is expected to create up to 1,450 high-paying jobs and generate about \$1 billion a year in direct and indirect economic impact for the state.¹¹⁷ The project could pump \$61 billion into the economy over the projected 60-year life of the mine, annual increases of up to \$113 million in state and local taxes, and \$200 million in federal taxes.¹¹⁸ Arizona is the nation's largest copper-producing state and has a very long history with copper mines and mining.



Giant shovel of an excavator used in African critical mineral mining operations.

ROSEMONT COPPER MINE

The Rosemont copper mine in the northern Santa Rita Mountains in Arizona received a setback when federal regulators rejected its mining company's request to reduce critical habitat for jaguars deemed endangered on land that overlaps the footprint of the proposed mine.¹¹⁹ Hudbay Minerals Inc. has been working for more than a decade to open the mine which would create thousands of jobs and bring billions in economic development to the region. The mine only needed about 6 percent of the land that had been excluded for the jaguars.

111 Nation World News, US House committee moves to block Rio Tinto's resolution mine, December 9, 2021, <https://nationworldnews.com/us-house-committee-moves-to-block-rio-tintos-resolution-mine/>

112 Cronkite News, Feds rescind OK for copper mine at Oak Flat, seek 'thorough review', March 1, 2021, <https://cronkitenews.azpbs.org/2021/03/01/feds-rescind-ok-for-copper-mine-at-oak-flat-seek-thorough-review/>

113 Ibid.

114 United States Department of Agriculture, Resolution Copper Project and Land Exchange Environmental Impact Statement, <https://www.resolutionmineeis.us/>

115 AZ Mirror, How the House reconciliation bill scraps Resolution Copper mine in Oak Flat, September 13, 2021, <https://www.azmirror.com/2021/09/13/how-the-house-reconciliation-bill-scraps-resolution-copper-mine-in-oak-flat/>

116 Reuters, Full 9th US Circuit to tackle complex Resolution Copper mining case, November 18, 2022, <https://www.reuters.com/markets/commodities/full-9th-us-circuit-tackle-complex-resolution-copper-mining-case-2022-11-18/>

117 Cronkite News, Feds rescind OK for copper mine at Oak Flat, seek 'thorough review', March 1, 2021, <https://cronkitenews.azpbs.org/2021/03/01/feds-rescind-ok-for-copper-mine-at-oak-flat-seek-thorough-review/>

118 Resolution Copper, Myths and Facts, <https://resolutioncopper.com/myth-and-facts/>

119 Cronkite News, Feds deal another setback to Rosemont mine by upholding jaguar habitat, September 3, 2021, <https://cronkitenews.azpbs.org/2021/09/03/feds-deal-another-setback-to-rosemont-mine-by-upholding-jaguar-habitat/>

Further, Tucson Arizona officials are trying to block operators of the Rosemont copper mine from storing water in a recharge facility the city co-owns. The contract would allow Rosemont to store up to 1,124 acre-feet of water—about 366 million gallons—at the facility each year from 2022 to 2032.¹²⁰ Hudbay Minerals Inc. pledged to return some of the 1.7 billion gallons of groundwater it plans to pump each year back into the aquifer. The city is considering options that include diverting water from its other recharge facilities to block Rosemont or take legal action.

The original proposed Rosemont mine is estimated to be a \$2 billion open-pit mining project and would add up to 2,500 jobs in an area with a high poverty rate for the 19 years where the mine is set to operate.¹²¹

In April 2022, it was announced that a Hudbay Minerals Inc. subsidiary will begin clearing and grading private land on the Santa Rita Mountains' western slope south of Tucson for a planned new mine with five open pits.¹²² Pima County regional flood control officials were notified that the company plans to start seeking environmental permits from state agencies for construction of the Rosemont Copper World project. Hudbay said it would strive to minimize environmental disturbances and comply with all government requirements.

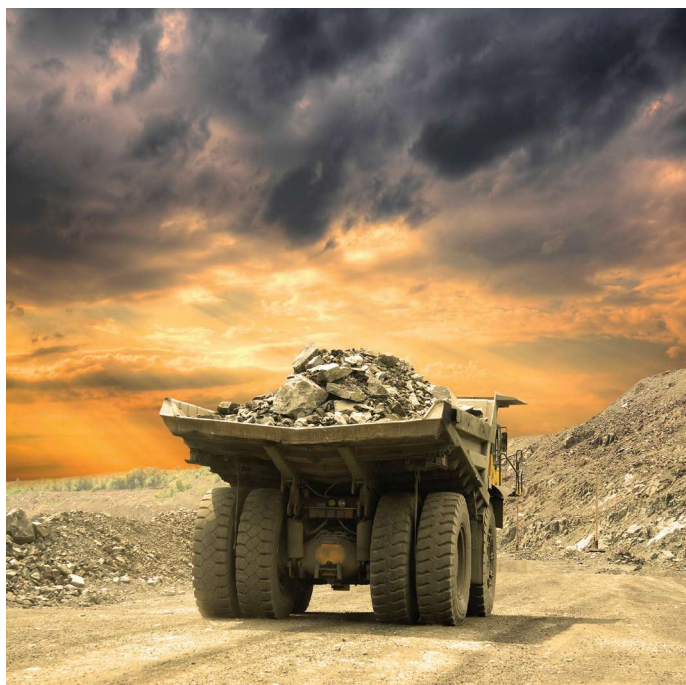
The organization Earth Justice has been fighting the Rosemont mine project since 2017, representing Indian Tribes that claim to have burial grounds in the area. Earth Justice sought a preliminary injunction to stop any digging from starting at the eastern mine. Instead of granting a preliminary injunction, the judge ruled on the merits of the Tribes' case, holding that the Forest Service made a "crucial error" by assuming Hudbay Minerals had a right to use public lands without any evidence of a valuable mineral deposit, and that this error "tainted the Forest Service's evaluation of the Rosemont Mine from the start." The judge prevented any mining activities from going forward, and called out the Forest Service for abdicating its duty to protect our public lands.¹²³

PEBBLE MINE

The Pebble copper and gold mine on state lands 100 miles from Bristol Bay, Alaska, had its permit application rejected in November 2020 by the Army Corps.^{124,125} The Pebble Mine also is rich in two important rare earth minerals, palladium and rhenium. It contains enough rhenium to supply the entire world's needs for nearly half a century.¹²⁶ Rhenium is used in the construction of military jet engines and as a catalyst in high-octane fuel combustion.¹²⁷

In January 2021, the Pebble Partnership requested the Army Corps to reverse its denial of the proposed mine's Clean Water Act dredge and fill permit. According to Northern Dynasty Minerals, that decision

is receiving new oversight and is likely to take a year or longer.¹²⁸ However, Biden's EPA indicated that, depending on the outcome



Heavy dump truck carrying ore from an opencast mining operation.

- 120 AZ Central, Tucson digs in against Rosemont copper mine in a dispute over a water storage project, January 31 2022, <https://www.azcentral.com/story/news/local/arizona-environment/2022/01/31/tucson-uses-dispute-over-water-recharge-renew-rosemont-opposition/9247404002/>
- 121 9 KGUN Tucson, Federal judge throws out approval to start construction on the Rosemont Mine, July 31, 2019, <https://www.kgun9.com/news/local-news/federal-judge-throws-out-approval-to-start-construction-on-the-rosemont-mine> ; AZ Central, Tucson digs in against Rosemont copper mine in a dispute over a water storage project, January 31, 2022, <https://www.azcentral.com/story/news/local/arizona-environment/2022/01/31/tucson-uses-dispute-over-water-recharge-renew-rosemont-opposition/9247404002/>
- 122 Tucson.com, Hudbay to clear land near Tucson for goal of 5 open-pit mines, April 6, 2022, https://tucson.com/news/local/subscriber/hudbay-set-to-clear-land-near-tucson-for-goal-of-5-open-pit-mines/article_82f4edb2-b21a-11ec-9637-0fe54ce05803.html
- 123 EarthJustice, Tribes Halt Major Copper Mine on Ancestral Lands in Arizona, November 7, 2022, <https://earthjustice.org/blog/2019-november/rosemont-mine-arizona-tribes-Tohono-Oodham>
- 124 Mining News North, Pebble Mine Death Grossly Exaggerated, August 24, 2020, <https://www.miningnewsnorth.com/story/2020/08/28/news/pebble-mine-death-grossly-exaggerated/6415.html>
- 125 National Fisherman, Pebble Mine owners discuss delay in appeals process, August 17, 2021, <https://www.nationalfisherman.com/alaska/pebble-mine-owners-discuss-delay-in-appeals-process>
- 126 Bloomberg, Why Palladium is Suddenly the Most Precious Metal, October 28, 2019, <https://www.bloomberg.com/news/articles/2019-10-28/why-palladium-is-suddenly-a-more-precious-metal-quicktake-k2ap4ryc>
- 127 Mining News, Rhenium—the hot superalloy element, June 22, 2020, <https://www.miningnewsnorth.com/page/rhenium-the-hot-superalloy-element/5748.html>
- 128 National Fisherman, Access Denied: Pebble Mine permit does not pass go, November 25, 2020, <https://www.nationalfisherman.com/alaska/access-denied-pebble-mine-permit-does-not-pass-go>

in the courts, it would reopen a proposed veto of the Pebble mine, which, if finalized, would effectively block its development on state-owned lands.¹²⁹ That process, started under the Obama administration, culminated in a proposed veto of the mine in 2015, before Pebble had even filed a permit application with the Army Corps.

President Biden's EPA, citing its authority under the 1972 Clean Water Act, proposed a legal determination that would ban the disposal of mining waste rock in the Bristol Bay watershed. The proposal would create permanent protections for the waters and wildlife of Bristol Bay, about 200 miles southwest of Anchorage.¹³⁰ It would prohibit disposing of mine-related waste within 308 square miles around the site of the proposed Pebble Mine project, an area about four times as large as Washington, D.C.

More than 600,000 people commented on the proposal. Many opposed the mine, though some tribes near the site favor the project, as does the State of Alaska. In late November 2022, Casey Sixkiller, the Region 10 EPA Administrator, sent a recommendation to EPA headquarters to veto the proposed mine.¹³¹ In January 2023, the EPA issued a final determination under the Clean Water Act that bans the disposal of mine waste in part of the bay's watershed. Determinations using the 1972 Clean Water Act are rare with only three issued in the past 30 years. The Pebble Limited Partnership is likely to appeal the determination.¹³²

ACCESS TO AMBLER MINING DISTRICT

Federal regulators recently suspended a right-of-way for a road in Alaska, previously granted by the Trump administration, which provided the state access to one of the world's largest mineral deposits including zinc and copper.¹³³ On March 11, 2022, the BLM notified the Alaska Industrial Development and Export Authority that it suspended a previously issued 50-year right-of-way that covers 25 miles of a proposed 211-mile road connecting the Ambler Mining District to Alaska's highway system. President Biden's BLM determined that the effects the proposed Ambler Road might have on subsistence uses were not properly evaluated and that tribes were not adequately consulted prior to issuing the right-of-way, despite a record of seven years of such evaluations and consultations. The State of Alaska deemed access was essential to its economic development promised in its Statehood Act.

BLM requested a remand to have time to supplement the administrative record. U.S. District Court Judge Sharon Gleason granted BLM's motion for voluntary remand without vacatur.¹³⁴ Since then, BLM has held public comments, is drafting a supplemental environmental impact statement, and studying preliminary comments to see if it needs to consider alternatives. The federal agency will issue its final decision on the proposed Ambler road project in the fourth quarter of 2023.¹³⁵ The Alaska Industrial Development and Export Authority had planned more than \$30 million worth of field work in 2022, half funded by the state-backed corporation and the other half by Ambler Metals, a joint venture owned by South32 Limited and Trilogy Metals. The field work would inform a budget for a final investment decision in 2024. In light of the remand, the partners—as well as NANA Regional Corporation, the Northwest Arctic Borough, and the State of Alaska—are reassessing AIDEA's proposed plan and budget.¹³⁶

PROPOSALS TO CHANGE THE GENERAL MINING ACT

Despite the difficulty of getting needed permits, as illustrated by the above mentioned projects, a number of Congressional lawmakers still want to make changes to the century-old General Mining Act of 1872 to make it more costly to mine for these metals in the United States. In the 117th Congress, former House Natural Resources Chairman Raúl Grijalva (D-AZ) and Senator Martin Heinrich (D-NM) introduced legislation,

129 E&E News, EPA revives Pebble mine veto, September 9, 2021, <https://www.eenews.net/articles/epa-revives-pebble-mine-veto/>

130 New York Times, Biden Administration Settling a Long Feud, Moves to Block a Mine in Alaska, May 25, 2020, <https://www.nytimes.com/2022/05/25/climate/pebble-mine-alaska-epa.html>

131 Alaska Public, EPA edges closer to banning Pebble Mine in Alaska. A veto is now just one step away. December, 1, 2022, <https://alaskapublic.org/2022/12/01/epa-edges-closer-to-banning-pebble-mine-in-alaska-a-veto-is-now-just-one-step-away/>

132 New York Times, EPA Blocks Long-Disputed Mine Project in Alaska, January 31, 2023, https://www.nytimes.com/2023/01/31/climate/pebble-mine-epa-decision.html?campaign_id=2&emc=edit_th_20230201&instance_id=84188&nl=todaysheadlines®i_id=63692790&segment_id=124063&user_id=edd9a99552656979b642d62e6445e311

133 Mining News, White House puts up and Ambler roadblock, March 14, 2022, <https://www.miningnewsnorth.com/story/2022/03/18/news/white-house-puts-up-an-ambler-roadblock/7297.html>

134 Alaska Business, Ambler Access Work Continues Despite Disappointing Ruling, May 26, 2022, <https://www.akbizmag.com/industry/mining/ambler-access-work-continues-despite-disappointing-ruling/>

135 Alaska Beacon, Bureau of Land Management Schedules Ambler Road Decision for Late 2023, November 17, 2022, <https://alaskabeacon.com/briefs/bureau-of-land-management-schedules-ambler-road-decision-for-late-2023/>

136 Alaska Business, Ambler Access Work Continues Despite Disappointing Ruling, May 26, 2022, <https://www.akbizmag.com/industry/mining/ambler-access-work-continues-despite-disappointing-ruling/>

both titled the “Clean Energy Minerals Reform Act,” that would fundamentally alter how U.S. mining companies are able to produce minerals on federal lands.¹³⁷

Representative Grijalva’s version would establish a federal leasing system for mining, analogous to the program for oil, gas, and coal companies that want to produce energy on public lands. Grijalva’s bill would establish a 12.5 percent royalty rate on new mining operations and an 8 percent royalty rate on existing mines. Currently, these mines operating on federal lands do not pay royalties to the government for locatable minerals,¹³⁸ and instead pay taxes on income and the employment the mine brings. The bill would also set “strong environmental standards” under the mining law “for mining activities and long-term reclamation” of closed or abandoned mines and require the government to consult with Indigenous tribes prior to “permitting mining activities that will impact tribal communities.”

Senator Heinrich’s version would require mining companies to pay a rate “not less than 5 percent and not greater than 8 percent based on the gross income” of mining production on federal land.¹³⁹ Gross income would not allow for the deduction of expenses related to mining and would seriously affect the competitiveness of U.S. mines on federal lands. The rate, however, “would not apply to mining operations already in commercial production or those with an approved plan of operations.” Senator Heinrich’s bill would also require “annual rent payments” for mineral claims on federal lands. The Heinrich proposal bill was co-sponsored by 6 other Democratic senators.

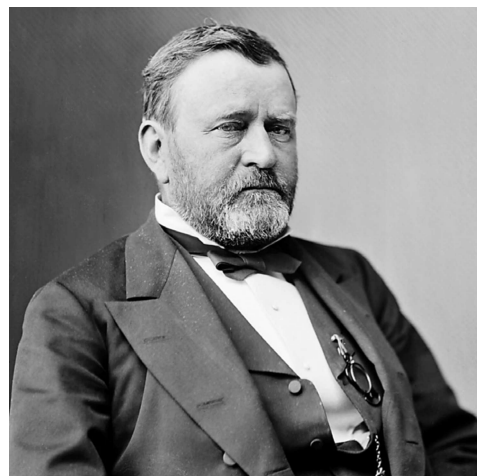
These two proposed bills would make it harder to mine or process these metals in the United States, which will only make energy more expensive for Americans. More likely, it will stop most mines dead in their tracks.

THE GENERAL MINING LAW OF 1872

The principal law affecting most hard rock mining on federal lands in the U.S. is the Mining Law of 1872 (Mining Law). It was passed the same year as the establishment of Yellowstone National Park, America’s first national park. Both were signed into law by President Ulysses S. Grant, with the National Park preceding the Mining Law by two months. Thus, the principles of protecting and preserving public lands for enjoyment as well as for providing for the public interest in economic development and access to valuable minerals were established at the same time.

The Congressional Research Service (CRS) wrote that the primary purposes of the 1872 law were to “promote mineral exploration and development on federal lands in the western United States, offer an opportunity to obtain a clear title to mines already being worked, and help settle the West.”¹⁴⁰

CRS goes on to say, “the 1872 Mining Law was one of the primary forces behind the development of mineral resources in the West, along with the industries and services that supported mineral production.”¹⁴¹ Major hard rock minerals developed in the West include copper, silver, gold, lead, zinc, molybdenum, and uranium. During the 19th century, major mining districts for silver and gold were developed under the Mining Law in Colorado, California, Idaho, and Nevada. Early in the 20th century, there were major developments of porphyry copper in Arizona. Large molybdenum and tungsten deposits in Colorado were also developed. The Mining Law continues to provide the structure for much of the Western mineral development on public domain lands. Western mining, although not as extensive as it once was, is still a major economic activity, and a high percentage of hard rock mining is on public lands.”



President Ulysses S. Grant, who signed the 1872 Mining Law.

The Mining Law has changed numerous times over its history.¹⁴² In 1920, the Mineral Leasing Act removed oil, gas, oil shale, phosphates, sodium, and certain other minerals on federal public domain lands from the claim-patent system of the 1872 Mining Law and set up a system of

137 E&E News, Citing ‘clean energy’, progressives mount mining law overhaul, April 26, 2022, <https://www.eenews.net/articles/citing-clean-energy-progressives-mount-mining-law-overhaul/>

138 Ibid.

139 Ibid.

140 Congressional Research Service, Mining on Federal Lands: Hardrock Minerals, July 17, 2009, <https://crsreports.congress.gov/product/pdf/RL/RL33908>

141 Congressional Research Service, Mining on Federal Lands, September 10, 2002, https://www.everycrsreport.com/files/20020910_IB89130_f99a9848eaea77d35f12f472a184809b6da6e665.pdf

142 Ibid.

leasing in which the federal government retains ownership of the leased lands. Coal, which previously had its own claim-patent law (the 1873 Coal Act), was also included in the 1920 Leasing Act. After 1955, common variety minerals such as sand, stone, gravel, cinders, and pumice were sold under the Materials Act of 1947, as amended. During the 1960s and 1970s, the Multiple Use Sustained Yield Act, Wilderness Act, National Forest Management Act, NEPA, and Federal Land Policy Management Act generally addressed environmental protection, multiple use, and management of federal land. By imposing new requirements on agency actions, and by withdrawing some federal lands from development, these acts have affected mineral development under both the leasing system and the Mining Law claim-patent system. The Mining Law contains no direct environmental controls, but mining claims are subject to all environmental laws as a precondition for development.

Between 1872 and 2000, only about 1.5 percent of total public lands transferred out of federal ownership had been patented for mining. About 3.3 million acres had transferred as a consequence of miners proving their claims and paying transfer fees to the treasury to develop mines. The other 98.5 percent were transferred under homestead entries, statehood grants, railroad grants, and other non-mineral public land laws.

THE REPEAL OF THE MINING LAW

Critics of the Mining Law have attempted to repeal it for decades, alleging that it should be changed to a leasing system akin to energy and that title to all lands should remain under the control of the federal government. This comes at a peculiar time, since adding new costs and regulations to mining would simply make mining more difficult in the U.S. at a time when demand for minerals is skyrocketing in response to the transition pursued by European and U.S. governments. As discussed, “green transition” technologies require multiples more mineral products than their carbon-based energy counterpart systems.

The Biden administration has pledged support for this repeal, despite their acknowledgement that there must be more investment in mining and minerals processing in the U.S. to provide the critical minerals necessary for their net zero ambitions. They are rebranding the repeal of the Mining Law as the “Clean Energy Minerals Reform Act,” to make it appear to make it easier to develop minerals in America when the legislation would actually make it harder to mine.¹⁴³

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In response, Congressman Pete Stauber (R-MN), Chairman of the House Energy and Minerals Subcommittee, offered an alternative name for the legislation: “...the UNclean Energy Minerals from China, Russia, and Child Slaves in the Congo Act?”¹⁴⁴

The U.S.—where the Mining Law’s critics argue the law makes it too easy to mine—is woefully inadequate in mining and mineral processing even to meet today’s needs, never mind the mineral needs of an energy transition requiring mountains of new minerals produced and processed at factors of larger quantities. The irony, of course, is that many of the same groups and elected representatives who want to repeal the Mining Law are also supportive of the shift away from hydrocarbons and towards a minerals and critical materials energy system. At that same time, the U.S. is nearly 4 times as dependent upon China for many of these essential minerals as we were ever dependent upon the Middle East for oil.

143 Representative Pete Stauber, Remarks from Energy and Mineral Resources Subcommittee Ranking Member Pete Stauber on Today’s Mining Hearing, May 12, 2022, <https://stauberforms.house.gov/news/email/show.aspx?ID=ZEXZATUKTUXDO>

144 Ibid.

AVERAGE LEAD TIMES FOR PROJECT DEVELOPMENT

Regulatory delays are one of the biggest barriers to new mining development in the United States. They raise costs, extend timelines, and threaten investor confidence. Because of this, the U.S. struggles to compete globally in the minerals marketplace, especially in comparison to countries like China which recognizes the strategic geopolitical advantage of dominating the market share of these critical materials and is developing these capacities at a rapid pace.

It takes 7 to 10 years for a mining project to gain the necessary permits to begin operations in the United States.¹⁴⁵ Even for countries with similar environmental standards to those of the United States, such as Australia and Canada, it takes only two years. What causes this massive difference in approval times? The answer is largely a regulatory one.

The United States legal system contains many jurisdictional layers, meaning that in many cases, there are federal, state, and local governments all in some way regulating the development of new resources. Federal law has preemption and supersedes state and local law and regulation when they are in conflict. When they aren't in conflict, this creates a multi-layered system of interlocking regulations that are incredibly difficult for developers to navigate. This is made even more difficult by complex codes set out by the various executive agencies that have authority to codify regulations on mining, most notable among them the Bureau of Land Management.¹⁴⁶

Legislative attempts to simplify the regulatory process and ensure that developers can operate with reasonable certainty regarding when their applications will be reviewed and responded to have been made, but to little avail.

There are many federal laws in place that affect mining development. Chief among these is the National Environmental Policy Act (NEPA), discussed in the next section, and the General Mining Law of 1872, examined earlier in this paper. But those two laws are just the beginning of the many laws and regulations that developers must comply with. These are just a few examples:

It takes 7 to 10 years for a mining project to gain the necessary permits to begin operations in the United States. Even for countries with similar environmental standards to those of the United States, such as Australia and Canada, it takes only two years. What causes this massive difference in approval times? The answer is largely a regulatory one.

NATIONAL ENVIRONMENTAL POLICY ACT

At first blush, it might seem like there is nothing objectionable to NEPA. After all, NEPA requires federal agencies to study the environmental impacts of their actions and does not necessarily require any changes to projects. The original purpose was to provide decision makers with adequate information to ultimately make a decision. But in practice, NEPA is now used to slow down projects that have a federal nexus and increase the costs of financing to an unsustainable level.

To understand how NEPA can be used to stop projects, consider the example of the Keystone XL pipeline:

- In July 2008, TransCanada announced its intention to build the Keystone XL pipeline from Canada to the United States.

145 Standards, Best Practices, & Guidance for Mineral Resources & Mineral Reserves, Comparison of reporting environments, August 2008, https://nma.org/wp-content/uploads/2021/05/Infographic_SNL_minerals_permitting_5.7_updated.pdf

146 ICLG, Mining and Regulations Law USA, 2022, <https://iclg.com/practice-areas/mining-laws-and-regulations/usa>

- In September 2008, because it crossed the U.S.-Canada border, they filed for a cross-border permit with the U.S. State Department.¹⁴⁷
- In January 2009, the U.S. State Department held the first of 20 scoping meetings for the Environmental Impact Statement for the pipeline.¹⁴⁸
- In April 2010, the U.S. State Department released a Draft Environmental Impact Statement (EIS) finding that Keystone XL would have “limited environmental impacts” and started accepting comments on the Draft EIS.
- In April 2011, the U.S. State Department released a supplemental Draft EIS.
- August 2011, the U.S. State Department releases a final EIS and starts its National Interest Determination.¹⁴⁹
- September 2011, the final EIS finds no major environmental risks
- November 2011, President Obama delays approval until after the 2012 election
- December 2011, Congress grows frustrated with delays in approving the Keystone XL pipeline and requires President Obama to make a decision within 60 days.
- January 2012, after over 3 years of study by the U.S. State Department, but compelled by law to issue a decision, President Obama denies the cross border permit citing inadequate time to complete environmental examination.¹⁵⁰
- In 2012, Nebraska holds a hearing on a new route for Keystone XL through Nebraska.
- In September 2012, TransCanada submits a new Keystone XL route through Nebraska for the U.S. State Department to study.
- January 2013, Nebraska’s governor approves a new route for Keystone XL through Nebraska.
- March 2013, the U.S. State Department releases a Draft Supplemental EIS finding the project again will not have a significant environmental impact.
- January 2014, the U.S. State Department released the Final Supplemental EIS, again finding that Keystone XL would have negligible effects on the environment.¹⁵¹
- November 2015, President Obama rejects TransCanada’s application to build the Keystone XL pipeline stating he did not think it was in the national interest.¹⁵²
- January 2017, President Trump signs an executive order to permit the Keystone XL pipeline.
- January 2021, President Biden revokes the Keystone XL presidential permit.
- In June 2021, TransCanada, now renamed TC Energy, terminates Keystone XL.



The end of a pipeline with nobody working on it.

A few notes about this timeline:

It took the U.S. State Department three years (from 2008 until 2011) to find that Keystone XL posed no significant environmental risks. In 2008

147 U.S. State Department, Record of Decision and National Interest Determination [HTML], <https://2012-keystonepipeline-xl.state.gov/nid/249254.htm#8>

148 U.S. Chamber of Commerce, Keystone XL: A Long Road to Approval, https://www.uschamber.com/assets/archived/images/00_energy_keystone_osfc_800px.jpg

149 U.S. State Department, Record of Decision and National Interest Determination [HTML], <https://2012-keystonepipeline-xl.state.gov/nid/249254.htm>

150 Suzanne Goldberg, Keystone XL pipeline: Obama rejects controversial project, Jan. 18, 2012, <https://www.theguardian.com/environment/2012/jan/18/obama-administration-rejects-keystone-xl-pipeline?newsfeed=true>

151 Institute for Energy Research, Keystone XL: State Department’s Latest Report Is Favorable, Feb. 4, 2014, <https://www.instituteforenergyresearch.org/fossil-fuels/gas-and-oil/keystone-xl-state-departments-latest-report-is-favorable/>

152 U.S. State Department, Keystone XL Pipeline Application, <https://2012-keystonepipeline-xl.state.gov/index.htm>

there were 170,000 miles of oil pipelines in the United States.¹⁵³ The risks were well known. And yet it took three years to study the environmental impacts of a state-of-the-art pipeline.

TransCanada submitted a new route for the Keystone XL pipeline through Nebraska in September 2012, and it took another 16 months to go through the NEPA process and find that—yet again—the pipeline posed negligible environmental impacts.

In 2013, President Obama stated that he won't approve the Keystone XL pipeline if it will "significantly exacerbate the problem of carbon pollution."¹⁵⁴ Despite the fact that the U.S. State Department's NEPA work concluded that Keystone XL would have a negligible impact on carbon emissions (because moving oil by pipelines is more energy and carbon dioxide-emissions efficient than moving oil by train or truck),¹⁵⁵ President Obama rejected the pipeline anyway on climate grounds.

The Obama administration used the NEPA process to delay making a decision on Keystone XL for more than four years. The president stated he would make the decision on climate grounds, but when the NEPA studies found insignificant climate impacts, he denied it anyway. President Trump tried to revive the project, but President Biden killed it for good.

With Keystone XL, the Obama administration abused the NEPA process to drive up the costs of building the pipeline by stalling for years and years. The environmental impacts were negligible from the start because there are already so many oil pipelines in the U.S., and pipelines are proven energy transport systems with the least possible impacts.

NEPA is manipulated in a similar manner to slow down mining or stop mining projects. The point of campaigns against economic investments is to lengthen the process for so long that the financial backers of the projects walk away. It has worked remarkably well in the United States as a device to stop economic development.

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CLEAN AIR ACT

Mining activities are also regulated under Title 30 of the Clean Air Act (CAA).¹⁵⁶ The Clean Air Act establishes the guidelines that each type of mineral processing must comply with, there are four broad categories, with the National Emission Standards for Hazardous Air Pollutants being the most stringent. These standards apply to hazardous materials and processes that involve heavy chemicals.

RESOURCE CONSERVATION AND RECOVERY ACT

The Resource Conservation and Recovery Act (RCRA) gives the EPA the authority to control hazardous wastes. An amendment to the law gives it the authority to control non-hazardous wastes. The EPA regulates the generation, transportation, storage, treatment, and disposal of these various wastes.¹⁵⁷

153 Pipeline and Hazardous Materials Safety Administration, Annual Report Mileage for Hazardous Liquid or Carbon Dioxide Systems, <https://www.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-hazardous-liquid-or-carbon-dioxide-systems>

154 Institute for Energy Research, It's Time for President Obama to Approve Keystone XL, July 30, 2015, <https://www.instituteforenergyresearch.org/fossil-fuels/gas-and-oil/keystone-xl-it-is-time-for-president-obama-to-approve-it/>.

155 Drew Johnson, Criticism of Keystone pipeline proving baseless, embarrassing, The Washington Times, June 9, 2015, <https://www.washingtontimes.com/news/2015/jun/9/drew-johnson-criticism-of-keystone-pipeline-provin/>

156 Office of the Law Revision Council, United States Code Title 30 <https://uscode.house.gov/browse/prelim@title30&edition=prelim>

157 United States Environmental Protection Agency, Summary of the Resource Conservation and Recovery Act 42 U.S.C. §6901 et seq. (1976), September 28, 2021, <https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act>

CLEAN WATER ACT

Under Section 402 of the Clean Water Act (CWA), mines are required to attain a National Pollution Discharge Elimination System permit in order to discharge wastewaters of any kind. This first requires a NEPA Environmental Impact Statement. This is another example of the interconnected nature of the various regulations that apply to mining activities. Additionally, to fill or dredge any waters or wetlands, mining projects must receive a permit under section 404 of the Clean Water Act.¹⁵⁸

TOXIC SUBSTANCES CONTROL ACT

The Toxic Substances Control Act (TSCA) regulated the “development and application of new and existing chemical substances.” Many of the chemicals and materials used in the processing of ores fall under TSCA regulation.¹⁵⁹

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

Under Section 108 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), passed in 1980, financial responsibility requirements for the risks posed by various sites are established. Establishing these CERCLA or “Superfund” sites, “gives EPA the authority to require that classes of facilities establish and maintain evidence of financial responsibility to cover the costs associated with releases or threatened releases of hazardous substances from their facilities.”¹⁶⁰ CERCLA defines hazardous substances broadly, and this includes the wastes of many mining, milling and smelter byproducts and wastes other regulations like the RCRA may not cover. Under this law, “Regulators have the authority to use special funds, undertake emergency responses, and hold all historical owners or contributors—principal responsible parties—liable for cleanup costs. The definitions of liability are very broad and controversial under CERCLA and provide regulators tremendous enforcement powers.”¹⁶¹

FEDERAL LAND POLICY AND MANAGEMENT ACT

The Federal Land Policy and Management Act (FPLMA) relates to land-use on federal lands and controls the way that the BLM and the Forest Service administer mining on public lands. According to the EPA:

“Under FLPMA, BLM and USFS land use decisions are subject to NEPA. Federal land managers generally require Plans of Operation, which include reclamation plans and describe details of the proposed operation. By describing these plans in a NEPA document, other federal and state regulatory agencies can comment on aspects of the project design that relate to their respective statutory authorities, regulatory requirements, or that pertain to their particular expertise.”¹⁶²

Given the incredible volume of interconnected regulations and agencies, even under a development-friendly administration, it would be expensive and time-consuming to get a mining project approved. Under an anti-development administration, the difficulty is only heightened. None of this is meant to imply that we shouldn’t operate mines in the safest and least impactful manner possible. It is meant to show the various ways that these rules and regulations have been

Given the incredible volume of interconnected regulations and agencies, even under a development-friendly administration, it would be expensive and time-consuming to get a mining project approved. Under an anti-development administration, the difficulty is only heightened.

158 United States Environmental Protection Agency, EPA’s Hardrock Mining Framework, September 1997, <https://www3.epa.gov/npdes/pubs/appc.pdf>

159 American Geosciences, What are environmental regulations on mining activities, <https://www.americangeosciences.org/critical-issues/faq/what-are-regulations-mining-activities#:~:text=The%20TSCA%2C%20passed%20in%201977,ores%2C%20are%20regulated%20under%20TSCA.>

160 United States Environmental Protection Agency, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Federal Facilities, <https://www.epa.gov/enforcement/comprehensive-environmental-response-compensation-and-liability-act-cercla-and-federal>

161 American Geosciences, What are environmental regulations on mining activities, <https://www.americangeosciences.org/critical-issues/faq/what-are-regulations-mining-activities#:~:text=The%20TSCA%2C%20passed%20in%201977,ores%2C%20are%20regulated%20under%20TSCA.>

162 United States Environmental Protection Agency, EPA’s Hardrock Mining Framework, September 1997, <https://www3.epa.gov/npdes/pubs/appc.pdf>

manipulated to discourage or stop mineral development altogether.

Attempts have been made to reduce the regulatory burden on developers and streamline the development process, but yet, no attempt has been able to successfully reconcile reasonable precautions for environmental protection with the need for a uniform and consistent system of application that allows for system confidence. Developers have no certainty over things like approval timelines, which makes the process unnecessarily more expensive, and excludes companies with fewer resources who could compete with clearer upfront costs from doing so.

Each of these laws, and the body of regulations relating to them, are subject to appeals and legal challenges by outside parties, providing ample opportunity for delay and increasing uncertainty. Given the significant volatility in minerals prices as demonstrated previously in this paper, investors face growing uncertainty if appellants to a mining project succeed in delaying or denying a mine. The U.S. has earned a reputation as a bad place to invest in a new mining project as a consequence of an almost limitless appeals and “lawfare” process., essentially weaponizing the intricacies of the law to block projects that should be approved on the merits.

INTERNATIONAL POLICY COMPARISONS

Beyond expanding domestic capacity, it may also be prudent for the United States to pursue an extension of our critical minerals’ capacity beyond China, especially in countries like Australia and Canada. The greater the supply of these minerals that comes from domestic, or more reliable international sources, the less reliant the U.S. becomes to the vacillations that could be incurred from sudden changes in our relationship with China.

Some legislative efforts to utilize the resources of our allies are underhanded, serving to block domestic production more than anything else. In February 2022, the White House released a fact sheet on “Securing a Made in America Supply Chain for Critical Minerals,”¹⁶³ which seeks to shore up domestic supply lines for these resources. The reasoning behind this was that “The U.S. is increasingly dependent on foreign sources for many of the processed versions of these minerals. Globally, China controls most of the market for processing and refining for cobalt, lithium, rare earths, and other critical minerals.” But a few months later, the Biden administration pivoted to a minerals policy more concerned with relying on our allies—Canada, Australia, Brazil, and others—than with building domestic supply.¹⁶⁴

Why is it that the U.S. has a far less robust mining industry than what is present in both Australia and Canada despite a wealth of mineral resources? The differences are largely because of regulation and investment policy.

One key difference among these three is in the matter of reporting requirements. When companies are seeking investment in mining projects, there are specific regulations around what information they are required to collect and report. Although all three countries have similar sets of guidance in place, in the U.S. there is an additional and more arduous layer in place on top of this shared one. In Canada, mining projects reporting requirements are regulated under National Instrument 43-101, the Standards of Disclosure for Mineral Projects in the country.¹⁶⁵ In Australia, a similar code, the JORC Code, is used.¹⁶⁶ This code is established by the Joint Ore Reserves Committee, and members include all relevant minerals and financial councils in the country. The U.S. has a code with similar requirements to both of these, the SME Guide for Reporting Exploration Results, Mineral Resources, and Mineral Reserves. But this code isn’t what is generally used in the regulation of U.S. reporting standards because the Securities and Exchange Commission does not acknowledge

Why is it that the U.S. has a far less robust mining industry than what is present in both Australia and Canada despite a wealth of mineral resources? The differences are largely because of regulation and investment policy.

163 The White House, FACT SHEET: Securing a Made in America Supply Chain for Critical Minerals, February 22, 2022, <https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals/>

164 Reuters, Exclusive: Biden looks abroad for electric vehicle metals, in blow to U.S. miners, May 25, 2021, <https://www.reuters.com/business/energy/biden-looks-abroad-electric-vehicle-metals-blow-us-miners-2021-05-25/>

165 Standards, Best Practices & Guidance for Mineral Resources Mineral Reserves, Comparison of reporting environments, August 2008, <https://mrmr.cim.org/en/library/magazine-articles/comparison-of-reporting-environments/>

166 Ibid.

these standards and uses its own Industry Guide 7 instead.¹⁶⁷ This code is both distinct from the other country's codes and does not recognize the same concepts. Most notably, instead of allowing a pre-feasibility study or other form of assessment of viability as Canada and Australia do, respectively, it requires a full feasibility study, which is a costly action to take prior to being able to access investment capital.

This difference in reporting requirements discourages domestic development. The United States reporting requirements for mining companies result in companies traded here looking worse than their global counterparts. The Toronto Stock Exchange and TSX Venture Exchange offer a different paradigm for this and is resultantly the exchange where 47 percent of the world's public mining companies are listed.¹⁶⁸

The U.S. and Canada are great examples of different mineral policies at play because of proximity and geological similarity, the key difference tends to be one of policy rather than of physical conditions. After China, Canada is the country that the United States is the most reliant on for critical mineral resources.¹⁶⁹

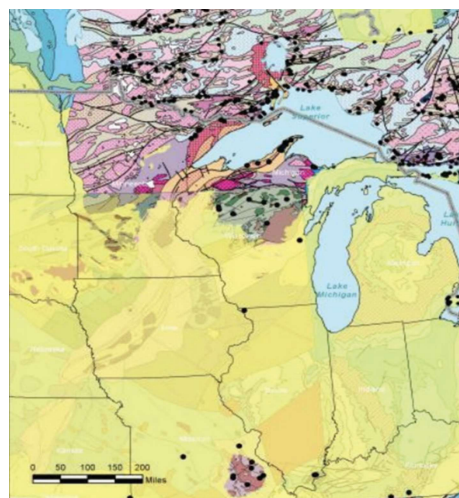
It's helpful to look at a visual of the difference in mineral activities between the two countries. For example, this map showcases the huge disparity in the number of mines in Ontario, Canada, and directly over the border in the United States.¹⁷⁰

Mines in Ontario vs. USA

No geological reason why mineral endowment stops at the U.S.- Canadian border

- Sedimentary rocks covering Precambrian basement
- Sedimentary rocks covering Precambrian basement

Source: [Groundbreaking! America's New Quest for Mineral Independence](#)



¹⁶⁷ Ibid.

¹⁶⁸ Toronto Stock Exchange, 2022 Guide to Listing, 2022, <https://www.tsx.com/ebooks/en/2022-guide-to-listing/28/>

¹⁶⁹ United States Geological Survey, Risk and Reliance: The U.S. Economy and Mineral Resources, April 12, 2017, <https://www.usgs.gov/news/featured-story/risk-and-reliance-us-economy-and-mineral-resources>

¹⁷⁰ Ann Bridges, Addendum to List of Figures in Groundbreaking! America's New Quest for Mineral Independence, <https://authorannbridges.files.wordpress.com/2018/11/website-references-to-figures.pdf>

CONCLUSION

There is a growing recognition that mining is critical for many evolving energy technologies, especially for electric vehicles, batteries, and renewable energy technologies. The International Energy Agency estimates that we would need 42 times as much lithium, 25 times as much graphite, 21 times as much cobalt, 19 times as much nickel, and 7 times as much rare earths as in 2020 in order to meet the policy goals of the Biden administration and our European counterparts.¹⁷¹

While there is a great need for these minerals, the United States is import-dependent on many of them. The USGS recently estimated that there were 50 minerals critical to the security of the United States. In 2021, imports made up more than half of the U.S. consumption for 47 of these mineral commodities, and the United States was 100 percent net import reliant for 17 of them.

While it may appear that the United States will have to import more minerals over time, America's incredible increase in oil and gas production over the last 15 years shows us what is possible if entrepreneurs were granted similar access to the mineral resources along with a regulatory environment that protects the environment and is amenable to experimentation at the same time. America's shale oil and gas deposits were well known to geologists for well over a century. The problem was making the oil and gas flow efficiently and economically. With the advent of horizontal drilling and hydraulic fracturing technologies, along with the right market conditions, America's oil and natural gas producers literally changed the world.

In 2008, U.S. oil production averaged 5 million barrels a day, but by 2019, the U.S. oil production averaged 12.3 million barrels a day.¹⁷² This is an astonishing 146 percent increase in oil production in only 11 years. This production growth was the result of technological improvements like hydraulic fracturing, better subsurface imaging, and improved directional drilling. But technological advancements were not enough. The revolution that made this dramatic growth possible happened almost exclusively on state and private lands, which allowed for the necessary experimentation without sacrificing the environment.

Around 2008, many people argued that we should “drill, baby, drill” domestically to lower oil and gasoline prices. Some experts disagreed that the U.S. could dramatically increase production through drilling. They were wrong.

There is no reason why we couldn't repeat this successful policy by streamlining regulations to allow more domestic mining and mining experimentation so the U.S. can experience a mining revolution like we saw with oil production. If we continue to hold ourselves back with excessive red tape, then we are deciding as a country that we should import more minerals and especially processed minerals. China currently dominates mineral processing, but there is no reason why the United States can't assume a leadership role in mining as well as mineral processing. A failure to do so will consign the U.S. to a future of economic and national security weaknesses Americans have never known.

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171 International Energy Agency, The Role of Critical Minerals in Clean Energy Transitions, May 2021, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>

172 Energy Information Administration, U.S. Field Production of Crude Oil, <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pets&s=mcrfps2&f=a>

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The Harvard Gazette

CAMPUS & COMMUNITY

Benita Kayembe takes hard look at hidden human cost of electric cars



"My parents said the biggest thing you can give to yourself is education, so I did everything I could to go to school," said Benita Kayembe, who at 19 moved from the DRC to California, despite knowing no English.

Kris Snibbe/Harvard Staff Photographer

Chan graduate's research focuses on deadly risks, exploitation faced by workers who mine key component of lithium-ion batteries in Republic of the Congo

Alvin Powell

Harvard Staff Writer

April 25, 2023

This story is part of a series of graduate profiles ahead of Commencement ceremonies.

For Benita Kayembe, global health ties together different threads of her life.

She grew up in the Democratic Republic of the Congo's Katanga Province, a region known for mining everything from copper and uranium to diamonds and cobalt — a key ingredient of lithium-ion batteries, which power the electric cars that many hope will soon supplant gasoline vehicles globally.

Though mines are an important part of the local economy, she said she grew up unaware of their prominence. But she knew health care was important. Her late father was a nurse who worked in a major mining company hospital, Gecamines Clinic. He also advocated for local people and started a small clinic in their town to meet unmet health needs. There she came to understand the importance of quality healthcare.

"He was a motivation for me," Kayembe said, "working at Gecamines, being involved in politics, and having a health care center. I saw people dying for no reason. The deaths of many people could have been prevented."

Kayembe, who is graduating this spring with a master's of science degree in global health and population from the Harvard T.H. Chan School of Public Health, took a winding road to Harvard. Despite knowing no English, at age 19 she moved from the DRC to California in 2013 for a chance at greater educational opportunities.

She stayed with family there and, with her parents' words on the importance of education firmly in mind, she took courses in English at a local job-training nonprofit and then moved on to economics at Cañada College, a public community college in Silicon Valley, earning an associate's degree.

She transferred to Cornell University and set her sights on international development, earning two bachelor's degrees by the time she graduated in 2020, in development sociology and in international agriculture and rural development. Along the way, she worked: as a server for a catering company, as a mentor to other community college students, and as a consultant, living in Phoenix and Seattle for a year after Cornell before deciding it was time to keep moving toward her dream.

"I knew that I wanted to pursue education because that was instilled in me," Kayembe said. "My parents said the biggest thing you can give to yourself is education, so I did everything I could to go to school."

It was at Cornell that Kayembe took her first global health course, which she felt finally provided an umbrella under which she could bring together the different threads of her studies and experiences.

"When I took my first introduction to global health, I knew that was what I would do," Kayembe said. "Global health gave me a different perspective on things I already experienced in my life, living in DRC and

in California, seeing how education impacts health, economics impacts policy, and global health is at the intersection of everything.”

For the last two years, Kayembe has been studying global health at the Harvard Chan School and says the people she’s met and the subjects she’s explored have helped her understand the forces that shape the health of people around the world and how those forces interact to affect lives.

She’s the president of the Harvard Africa Health Forum, founded a podcast dedicated to diverse voices in global health, and was a panelist at the Prince Mahidol Award Conference in Thailand, where she presented the results of research last summer that took her back to DRC for the first time in a decade.

She was happy to visit family while she was there, but the focus of that trip was the independent cobalt miners who operate outside of the operations of large companies. This informal sector is made up of tens of thousands of workers — including between 10,000 and 17,000 children — and accounts for about 20 percent of DRC’s cobalt production.

The nation’s cobalt industry, which produces about 70 percent of the global supply, has drawn more attention in recent years as demand for the mineral has increased. It is, after all, a key component in the batteries that power a variety of popular consumer products, including computers, cellphones, and electric vehicles. But analysts say a significant part of the demand is because of surging electric car sales amid rising signs of climate change.

Miners toil with little protection, and the work is hazardous. According to media reports, in 2019, 43 informal miners were killed in the DRC when a copper and cobalt mine collapsed; in 2020, 50 were killed after a gold mine shaft collapsed; in 2021, 12 died in a landslide at an informal gold mine; and in March 2023, two miners died in a collapse at one mine, while nearby, nine others were rescued after two days underground when the mine they were working in collapsed after heavy rain.

Spoils from mining can also be toxic. In 2021, 12 people were killed and 4,500 sickened when toxic metals from a diamond mine in Angola spilled into the Kasai River and flowed into DRC.

Kayembe, supported by a Rose Service Learning Fellowship, worked on the project in collaboration with Tony Kitenge at the Institut Supérieur des Techniques Médicales de Lubumbashi, who assisted her in getting access to the miners and the sites.

When she sat down with people and asked about their lives, Kayembe said she was surprised at how willing they were to share their experiences working all day to extract the ore from which cobalt can be separated.

During the 45 or so interviews she conducted, she learned that these miners are pushed into the work by economic pressures and subject to exploitation by systemic corruption. They often work with rudimentary tools or bare hands; they have no protective equipment; and the work is sometimes done by families. She saw kids as young as 5 cleaning off the minerals their mothers found. The mining sites had no schools, healthcare centers, or even facilities as rudimentary as toilets nearby.

“I grew up in Katanga six hours from a cobalt mine,” Kayembe said. “I grew up in a family in a community shielded from other realities.”

Jesse Bump, executive director of the Takemi Program in International Health at the Chan School and lecturer on global health policy, advised Kayembe on the project, encouraging her to forge ahead on work that he said “illuminates a vast universe of harm.”

Bump praised the breadth of experience and scholarship that Kayembe can bring to bear and said all of that gives her the opportunity to do meaningful work in places where health ills are significant yet often missed because of inaccessibility and cultural and language barriers. To Kayembe, he said, those are no barriers at all.

“As a Congolese citizen,” Bump said, “she has a life experience that goes to the core of what we’re studying in global health: What are the causes of inequality? What are the skills you need to interrogate that?”

“Much of what we do in global health is predicated on the reality that health is personal, and yet to confront that on a global scale often requires a tool kit that is somewhat reductionist: We do a lot of counting and calculating and then make assumptions based on our best estimates and surveys about what things must be like and what might be needed.

“But Benita can shortcut that in the Congo because she speaks the languages, knows the culture, and illuminates a set of dynamics that would resist interrogation by methods that are much more common here. What you have in her work is exactly the kind of work we should be doing, and exactly the kind of person who should be doing it.”

And Kayembe plans on continuing. She’s certain she wants her work to benefit people in disadvantaged communities in the DRC, though she confesses she’s not certain what that means for the months and years after graduation. She expects to work for a time and is already considering whether a Ph.D. program might be the right next step. What she’s sure of is that the need for artisanal miners will only grow as the world charges forward with electrification. She also knows she doesn’t want them to be an afterthought in the push for a more sustainable planet.

“I might be enjoying an electric car,” Kayembe said, “but somewhere someone is dying.”

The Dark Side of Solar Power

by Atalay Atas, Serasu Duran, and Luk N. Van Wassenhove

June 18, 2021



HollenderX2/Getty Images

Summary. Solar energy is a rapidly growing market, which should be good news for the environment. Unfortunately there's a catch. The replacement rate of solar panels is faster than expected and given the current very high recycling... [more](#)

It's sunny times for solar power. In the U.S., home installations of solar panels have fully rebounded from the Covid slump, with analysts predicting more than 19 gigawatts of total capacity installed, compared to 13 gigawatts at the close of 2019. Over the next 10 years, that number may quadruple, according to industry

research data. And that's not even taking into consideration the further impact of possible new regulations and incentives launched by the green-friendly Biden administration.

Solar's pandemic-proof performance is due in large part to the Solar Investment Tax Credit, which defrays 26% of solar-related expenses for all residential and commercial customers (just down from 30% during 2006–2019). After 2023, the tax credit will step down to a permanent 10% for commercial installers and will disappear entirely for home buyers. Therefore, sales of solar will probably burn even hotter in the coming months, as buyers race to cash in while they still can.

Tax subsidies are not the only reason for the solar explosion. The conversion efficiency of panels has improved by as much as 0.5% each year for the last 10 years, even as production costs (and thus prices) have sharply declined, thanks to several waves of manufacturing innovation mostly driven by industry-dominant Chinese panel producers. For the end consumer, this amounts to far lower up-front costs per kilowatt of energy generated.

This is all great news, not just for the industry but also for anyone who acknowledges the need to transition from fossil fuels to renewable energy for the sake of our planet's future. But there's a massive caveat that very few are talking about.

Panels, Panels Everywhere

Economic incentives are rapidly aligning to encourage customers to trade their existing panels for newer, cheaper, more efficient models. In an industry where circularity solutions such as recycling remain woefully inadequate, the sheer volume of discarded panels will soon pose a risk of existentially damaging proportions.

To be sure, this is not the story one gets from official industry and government sources. The International Renewable Energy Agency (IRENA)'s official projections assert that "large amounts

of annual waste are anticipated by the early 2030s” and could total 78 million tonnes by the year 2050. That’s a staggering amount, undoubtedly. But with so many years to prepare, it describes a billion-dollar opportunity for recapture of valuable materials rather than a dire threat. The threat is hidden by the fact that IRENA’s predictions are premised upon customers keeping their panels in place for the entirety of their 30-year life cycle. They do not account for the possibility of widespread early replacement.

Our research does. Using real U.S. data, we modeled the incentives affecting consumers’ decisions whether to replace under various scenarios. We surmised that three variables were particularly salient in determining replacement decisions: installation price, compensation rate (i.e., the going rate for solar energy sold to the grid), and module efficiency. If the cost of trading up is low enough, and the efficiency and compensation rate are high enough, we posit that rational consumers will make the switch, regardless of whether their existing panels have lived out a full 30 years.

As an example, consider a hypothetical consumer (call her “Ms. Brown”) living in California who installed solar panels on her home in 2011. Theoretically, she could keep the panels in place for 30 years, i.e., until 2041. At the time of installation, the total cost was \$40,800, 30% of which was tax deductible thanks to the Solar Investment Tax Credit. In 2011, Ms. Brown could expect to generate 12,000 kilowatts of energy through her solar panels, or roughly \$2,100 worth of electricity. In each following year, the efficiency of her panel decreases by approximately one percent due to module degradation.

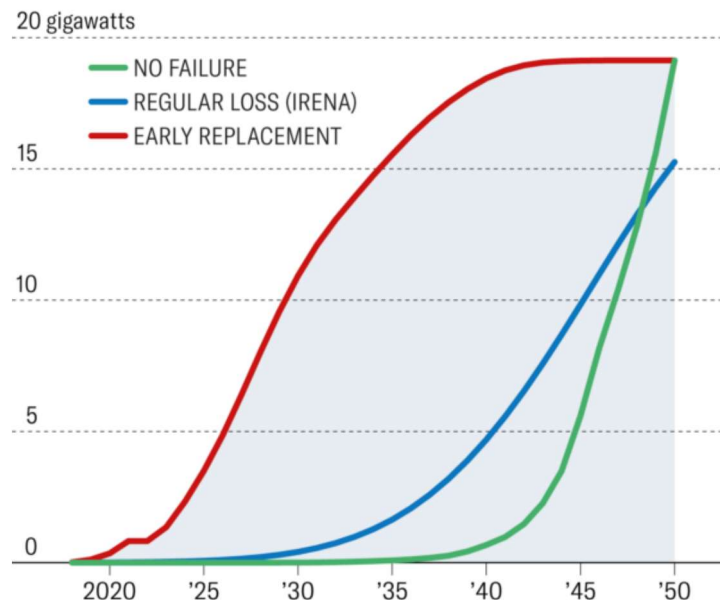
Now imagine that in the year 2026, halfway through the life cycle of her equipment, Ms. Brown starts to look at her solar options again. She’s heard the latest generation of panels are cheaper and more efficient — and when she does her homework, she finds that that is very much the case. Going by actual current projections,

the Ms. Brown of 2026 will find that costs associated with buying and installing solar panels have fallen by 70% from where they were in 2011. Moreover, the new-generation panels will yield \$2,800 in annual revenue, \$700 more than her existing setup when it was new. All told, upgrading her panels now rather than waiting another 15 years will increase the net present value (NPV) of her solar rig by more than \$3,000 in 2011 dollars. If Ms. Brown is a rational actor, she will opt for early replacement. And if she were especially shrewd in money matters, she would have come to that decision even sooner — our calculations for the Ms. Brown scenario show the replacement NPV overtaking that of panel retention starting in 2021.

The Solar Trash Wave

According to our research, cumulative waste projections will rise far sooner and more sharply than most analysts expect, as the below graph shows. The green “no failure” line tracks the disposal of panels assuming that no faults occur over the 30-year life cycle; the blue line shows the official International Renewable Energy Agency (IRENA) forecast, which allows for some replacements earlier in the life cycle; and the red line represents waste projections predicted by our model.

Cumulative capacity



Source: International Renewable Energy Agency, Electricity Data Browser, Global Solar Atlas

If early replacements occur as predicted by our statistical model, they can produce 50 times more waste in just four years than IRENA anticipates. That figure translates to around 315,000 metric tonnes of waste, based on an estimate of 90 tonnes per MW weight-to-power ratio.

Alarming as they are, these stats may not do full justice to the crisis, as our analysis is restricted to residential installations. With commercial and industrial panels added to the picture, the scale of replacements could be much, much larger.

The High Cost of Solar Trash

The industry's current circular capacity is woefully unprepared for the deluge of waste that is likely to come. The financial incentive to invest in recycling has never been very strong in solar. While panels contain small amounts of valuable materials such as silver, they are mostly made of glass, an extremely low-value material. The long life span of solar panels also serves to disincentivize innovation in this area.

As a result, solar's production boom has left its recycling infrastructure in the dust. To give you some indication, First Solar is the sole U.S. panel manufacturer we know of with an up-and-running recycling initiative, which only applies to the company's own products at a global capacity of two million panels per year. With the current capacity, it costs an estimated \$20–\$30 to recycle one panel. Sending that same panel to a landfill would cost a mere \$1–\$2.

The direct cost of recycling is only part of the end-of-life burden, however. Panels are delicate, bulky pieces of equipment usually installed on rooftops in the residential context. Specialized labor is required to detach and remove them, lest they shatter to smithereens before they make it onto the truck. In addition, some governments may classify solar panels as hazardous waste, due to

the small amounts of heavy metals (cadmium, lead, etc.) they contain. This classification carries with it a string of expensive restrictions — hazardous waste can only be transported at designated times and via select routes, etc.

The totality of these unforeseen costs could crush industry competitiveness. If we plot future installations according to a logistic growth curve capped at 700 GW by 2050 (NREL's estimated ceiling for the U.S. residential market) alongside the early-replacement curve, we see the volume of waste surpassing that of new installations by the year 2031. By 2035, discarded panels would outweigh new units sold by 2.56 times. In turn, this would catapult the LCOE (levelized cost of energy, a measure of the overall cost of an energy-producing asset over its lifetime) to four times the current projection. The economics of solar — so bright-seeming from the vantage point of 2021 — would darken quickly as the industry sinks under the weight of its own trash.

Who Pays the Bill?

It will almost certainly fall to regulators to decide who will bear the cleanup costs. As waste from the first wave of early replacements piles up in the next few years, the U.S. government — starting with the states, but surely escalating to the federal level — will introduce solar panel recycling legislation.

Conceivably, future regulations in the U.S. will follow the model of the European Union's WEEE Directive, a legal framework for the recycling and disposal of electronic waste throughout EU member states. The U.S. states that have enacted electronics-recycling legislation have mostly cleaved to the WEEE model. (The Directive was amended in 2014 to include solar panels.) In the EU, recycling responsibilities for past (historic) waste have been apportioned to manufacturers based on current market share.

A first step to forestalling disaster may be for solar panel producers to start lobbying for similar legislation in the United States immediately, instead of waiting for solar panels to start

clogging landfills. In our experience drafting and implementing the revision of the original WEEE Directive in the late 2000s, we found one of the biggest challenges in those early years was assigning responsibility for the vast amount of accumulated waste generated by companies no longer in the electronics business (so-called orphan waste).

In the case of solar, the problem is made even thornier by new rules out of Beijing that shave subsidies for solar panel producers while increasing mandatory competitive bidding for new solar projects. In an industry dominated by Chinese players, this ramps up the uncertainty factor. With reduced support from the central government, it's possible that some Chinese producers may fall out of the market. One of the reasons to push legislation now rather than later is to ensure that the responsibility for recycling the imminent first wave of waste is shared fairly by makers of the equipment concerned. If legislation comes too late, the remaining players may be forced to deal with the expensive mess that erstwhile Chinese producers left behind.



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But first and foremost, the required solar panel recycling capacity has to be built, as part of a comprehensive end-of-life infrastructure also encompassing uninstallation, transportation, and (in the meantime) adequate storage facilities for solar waste. If even the most optimistic of our early-replacement forecasts are accurate, there may not be enough time for companies to accomplish this alone. Government subsidies are probably the only way to quickly develop capacity commensurate to the

magnitude of the looming waste problem. Corporate lobbyists can make a convincing case for government intervention, centered on the idea that waste is a negative externality of the rapid innovation necessary for widespread adoption of new energy technologies such as solar. The cost of creating end-of-life infrastructure for solar, therefore, is an inescapable part of the R&D package that goes along with supporting green energy.

It's Not Just Solar

The same problem is looming for other renewable-energy technologies. For example, barring a major increase in processing capability, experts expect that more than 720,000 tons worth of gargantuan wind-turbine blades will end up in U.S. landfills over the next 20 years. According to prevailing estimates, only five percent of electric-vehicle batteries are currently recycled — a lag that automakers are racing to rectify as sales figures for electric cars continue to rise as much as 40% year-on-year. The only essential difference between these green technologies and solar panels is that the latter doubles as a revenue-generating engine for the consumer. Two separate profit-seeking actors — panel producers and the end consumer — thus must be satisfied in order for adoption to occur at scale.

...

None of this should raise serious doubts about the future or necessity of renewables. The science is indisputable: Continuing to rely on fossil fuels to the extent we currently do will bequeath a damaged if not dying planet to future generations. Compared with all we stand to gain or lose, the four decades or so it will likely take for the economics of solar to stabilize to the point that consumers won't feel compelled to cut short the life cycle of their panels seems decidedly small. But that lofty purpose doesn't make the shift to renewable energy any easier in reality. Of all

sectors, sustainable technology can least afford to be shortsighted about the waste it creates. A strategy for entering the circular economy is absolutely essential — and the sooner, the better.

AA

Atalay Atasu is a professor of technology and operations management and the Bianca and James Pitt Chair in Environmental Sustainability at INSEAD.

SD

Serasu Duran is a professor at the University of Calgary's Haskayne School of Business in Calgary, Alberta.

LW

Luk N. Van Wassenhove is the Henry Ford Chaired Professor of Manufacturing, Emeritus, at INSEAD and leads its Humanitarian Research Group and its Sustainable Operations Initiative.

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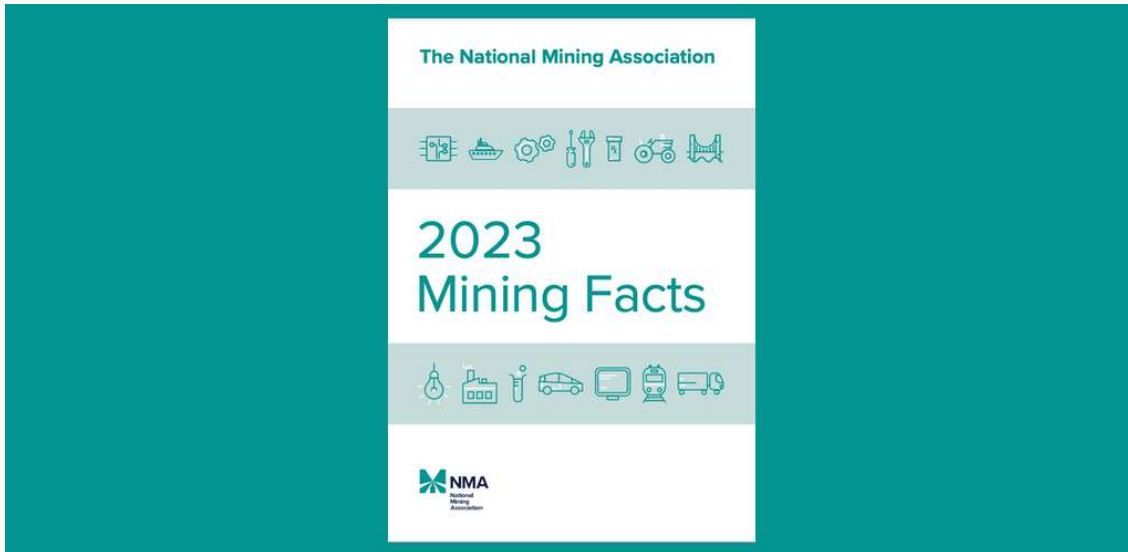


The Circular Business Model



PODCAST
Workplace Design, Post-Pandemic (Back to Work, Better)





This resource will provide you a guide by the numbers on the importance of the domestic mining industry, for example:

- **#1** – China is the #1 supplier of nonfuel mineral commodities for which the United States was 50 percent + reliant in 2022
 - **40,000 pounds** – Average annual amount every American uses of newly mined materials
 - **88%** – Percent increase in the number of minerals for which the U.S. is entirely import dependent since 1995
 - **\$6 billion** – Value of minerals the U.S. imports from foreign countries, despite being home to reserves estimated at over \$6 trillion
 - **384** – Number of new mines needed by 2035 to fulfill battery demands
 - **\$119 billion** – Annual U.S. revenues generated through mining
-

- **1,000%** – Projected increase in demand for minerals needed for future energy technologies, according to the Center for Strategic and International Studies
 - **4,000%** – Increase in lithium demand by 2040 under the International Energy Agency's Sustainable Development Scenario
 - **4.7 tons** – Amount of copper needed for a single wind turbine
 - **330 metric tons** – Amount of gold the technology sector required in 2021
 - **\$2.45 billion** – Amount of platinum, which is used in 20 percent of all manufactured goods, that the U.S. imported from Russia in 2021
 - **183 pounds / 439 pounds** – Amount of copper used on average in electric vehicles / Amount of copper used in the average American home
 - **67%** – Portion of global zinc production used to coat steel for infrastructure and manufacturing to make it resistant to corrosion
 - **105%** – Increase in global nickel demand by 2030 for transportation technologies
 - **38%** – Portion of US electricity that comes from coal and nuclear energy powered by uranium
 - **70%** – Portion of the world's steel that requires coal for production
-

- **35%** – CO2 emission reductions achieved through high efficiency, low emissions coal plants
- **\$100 billion** – Amount coal plant owners have invested in advanced emissions control technologies over the last 20 years
- **\$3 million** – Acres of mined land that have been restored by U.S. mining companies
- **1.2 million +** – Number of direct and indirect jobs generated by the mining industry
- **\$85,000 +** – Average annual salary for a U.S. miner (26% above avg. U.S. wage)
- **\$18 billion** – Total federal, state, and local taxes attributable to mining jobs

Below are a few of our issue-specific factsheets addressing key issues in the mining sector:

- [Permitting Reform](#)
- [Regulating U.S. Mining](#)
- [Strengthening America's Infrastructure](#)
- [EPA's Regulatory Agenda Implications](#)

The NMA also has a range of video resources available as well:

- NMA's members are [committed to operating in accordance with the highest environmental, labor and safety standards in the world](#).
 - There's strong, bipartisan recognition of the [need to address the nation's self-imposed permitting challenges so the U.S. can meet skyrocketing mineral demand](#).
-

- Please find more information at nma.org.

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When you think of mining, please think of the NMA. We want to be a resource for you this Congress.

Sincerely,

A handwritten signature in black ink, appearing to read "Ryan Jackson", enclosed in a white rectangular box.

Ryan Jackson

Senior Vice President for Government and Political Affairs
rjackson@nma.org

CIRCUIT BREAKER:

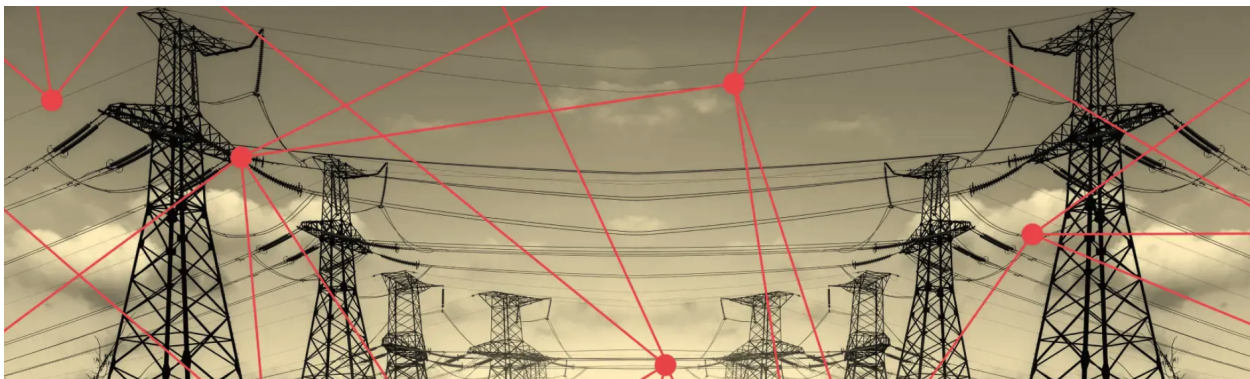
Electrification won't break the grid, it will make it smarter.

By Sam Calisch (Rewiring America); Cora Wyent (Rewiring America)

July 4, 2022

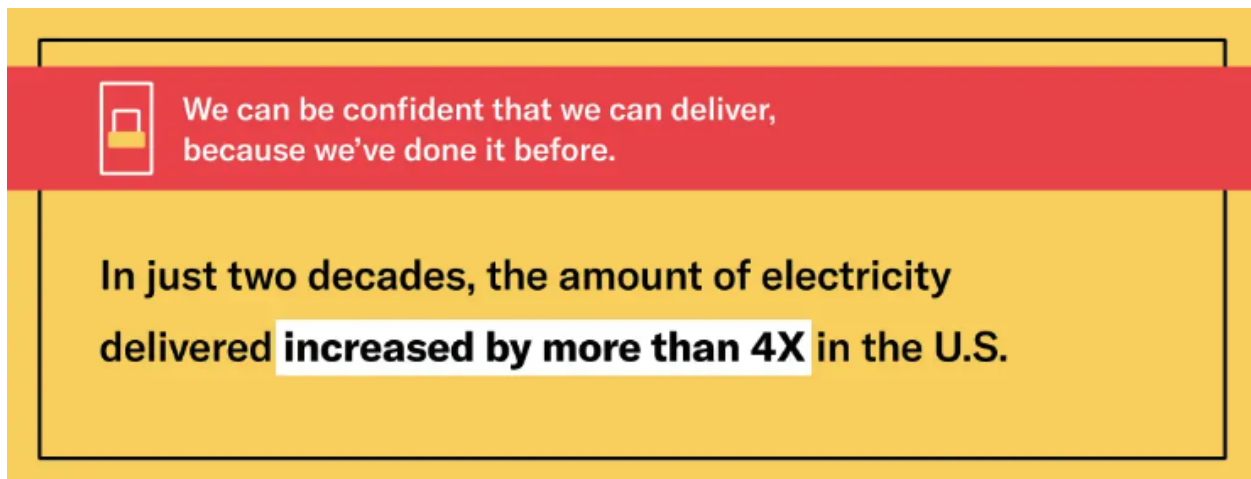
Focus points:

- To meet our climate goals, we'll need to deliver two to three times as much electricity as today. Fortunately, we've scaled the grid faster than this before and can do it again [1].
- Smart grid technologies can allow more electricity to be delivered by the same infrastructure, reducing the amount of new grid build-out and increasing resilience.
- Smart electric panels can enable whole home electrification, including EVs and heat pumps, largely without upgrading upstream infrastructure like wires or transformers, cutting the cost and time required for electrification.



To meet our climate goals, we must electrify nearly everything in our economy. That will require delivering about two to three times more electricity than we do today [2].

A share of this will come from clean solar energy generated right on our rooftops [3], but our grid will also need to grow significantly to deliver the remaining electricity demand. Skeptics of electrification say the grid won't be able to handle this [4], but history says otherwise. In just one decade, between 1950 and 1960, the amount of electricity delivered more than doubled in the U.S, and by 1970 it had more than doubled again [5], largely in response to the proliferation of uses for electricity beyond lighting [6]. As American households now similarly spur increased electricity demand to power electric vehicles and heat pumps [7], we can be confident that we can deliver, because we've done it before.



 We can be confident that we can deliver,
because we've done it before.

**In just two decades, the amount of electricity
delivered increased by more than 4X in the U.S.**

In order to grow the grid as efficiently and effectively as possible, we can leverage a host of technologies that make it smarter, more responsive and capable of delivering more electricity [8]. The cost of infrastructure – like wires and transformers – is driven by assumptions about worst case demand: the grid is typically designed to operate even if all consumers were to turn on nearly all of their devices at the same time. Because these events are so exceedingly rare, we aren't using these components to their full potential. A smarter grid would use the inherent flexibility of electricity demand [9] to avoid these situations altogether, allowing more electricity to be delivered by the same infrastructure.

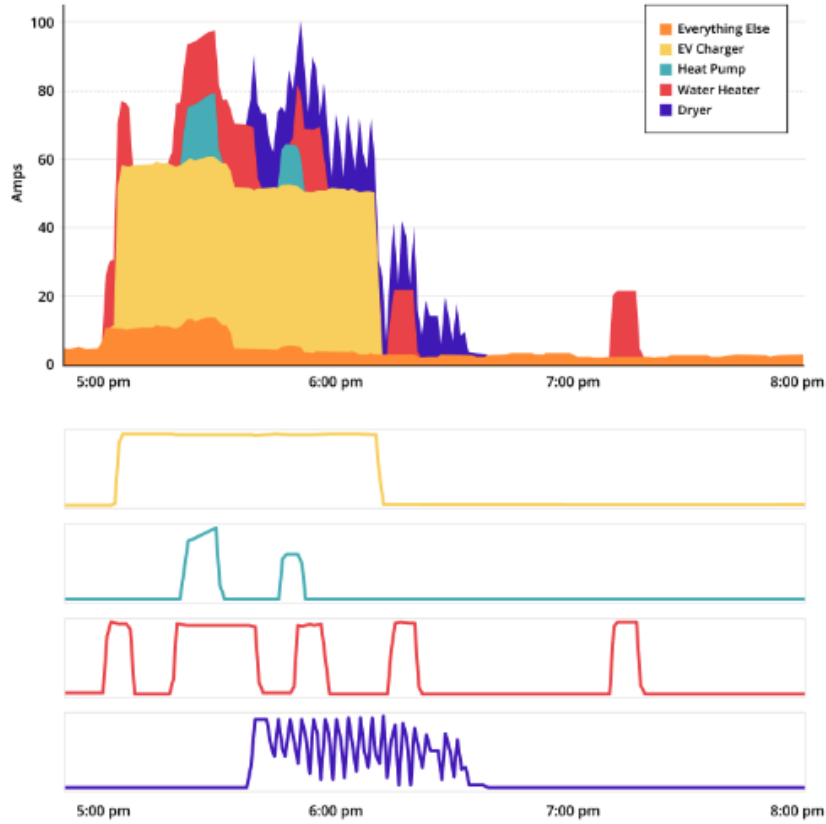
While this may seem far-away and complex, there are significant opportunities hiding right in our basements and utility closets, embodied in the humble electrical panel

[10]. These pieces of infrastructure are responsible for safely regulating the flow of electricity between the grid and loads in a building.

As homes electrify, adopting electric vehicles, heat pumps and electric stoves in place of fossil fuel machines, they may demand more electricity than the panel was originally designed for. Like other grid infrastructure, panels are sized for the peak electricity load: roughly the amount of electricity required if your electric vehicles, heat pump, water heater, stove and everything else is turned on at the same time [11]. This peak load, however, is 10-20 times higher than the average load over time [12]. Thus, if we can better manage peak events, substantially more electricity can be delivered without increasing panel capacity.

Fortunately, we have “smart panels”, which are electrical panels designed to do just this, measuring the flow of electricity and allowing individual circuits to be automatically turned on and off to regulate a home’s peak electricity demand. As an example, in Figure 1 at left, we show a peak event from an actual electrified home around dinner time, using data provided by SPAN, a leading manufacturer of smart panels. The householder likely arrived home from work, plugged in their car, started a load of laundry and turned up the thermostat. As a result, the total electricity drawn from the grid exceeded 80 amps for several minutes [13], exceeding a safe limit for a 100 amp panel [14]. If not for a smart panel, this household would likely have needed a 200 amp service upgrade when electrifying. On the right, we see the same event as could be mediated by the smart panel. By shifting 34 minutes of EV charging (shown in orange) with no inconvenience to the householder, the maximum load is kept below that 80 amp threshold at all times [15]. In data from SPAN’s electrical panels covering all contiguous U.S. climate zones, over 80 percent of peak events [16] were less than 12 minutes long, and shifting the operation of just one of the water heater, dryer, EV charger, or HVAC system can mitigate 90 percent of all peak events. These data indicate that the vast majority of peak loads could be shifted without any noticeable effect to the household.

A real-world peak event of over 80 amps around dinner time, caused by an EV charger, heat pump, water heater, and dryer all cycling on at the same time.



Sam Callisch, Rewiring America, Data from SPAN.Io

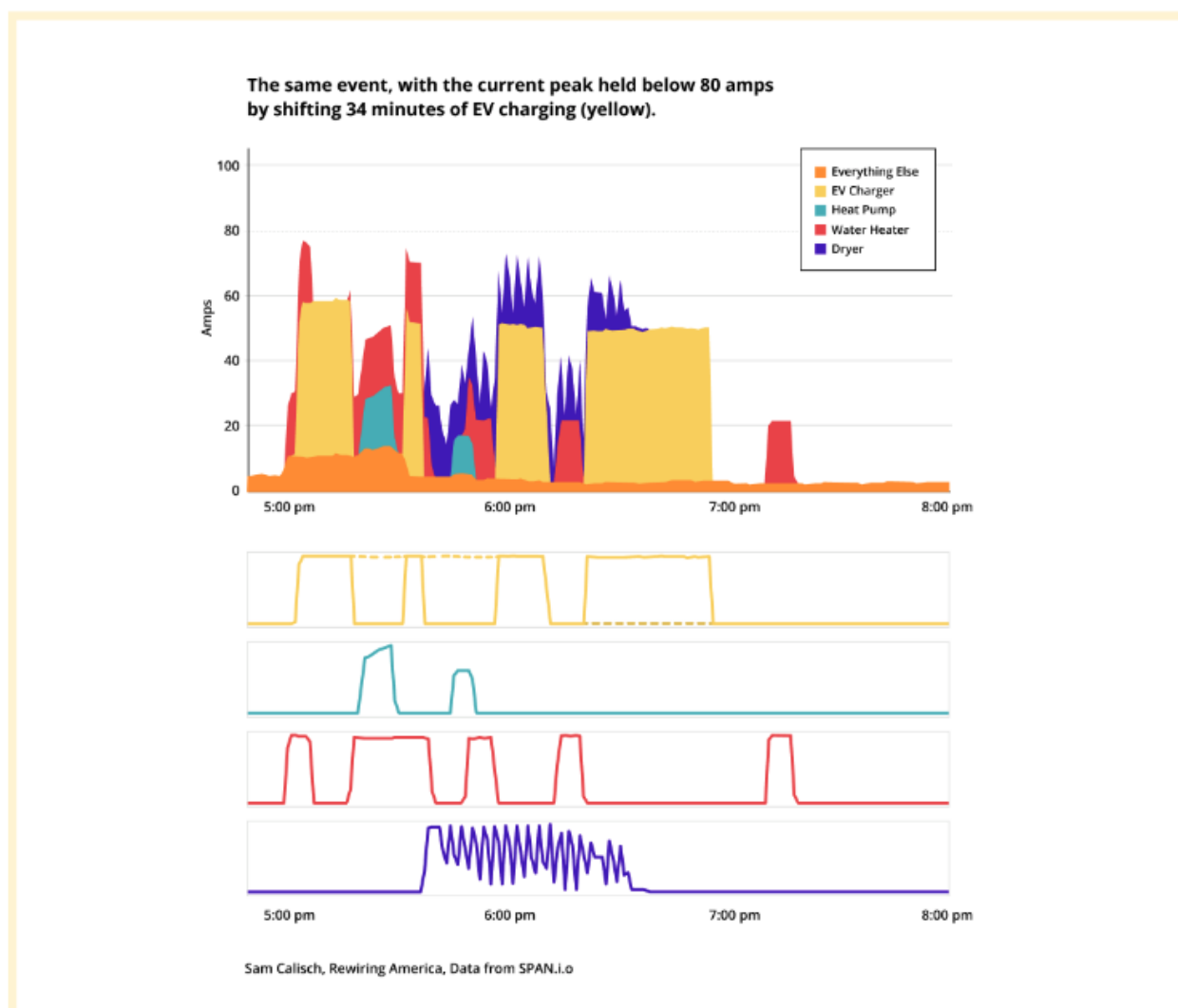


Figure 1: Top) A real-world peak event of over 80 amps around dinner time, caused by an EV charger, heat pump, water heater, and dryer all cycling on at the same time. Bottom) The same event, with the current peak held below 80 amps by shifting 34 minutes of EV charging (orange). Data provided by Span.IO, Inc. and analyzed by Rewiring America.

Today, approximately 50-60 million single-family homes (or approximately 60-70 percent) have electrical panels with ratings less than 200 amps [17]. If these households fully electrify (including two electric vehicle chargers, heat pump HVAC, heat pump water heating, electric range, and electric dryer), it is likely that most will need a new, larger electrical panel [18]. If this new panel is not a smart panel, a further upgrade to the incoming electrical service (that is, the wires carrying electricity from the street) may also be required. While buying a smart panel is

incrementally more expensive than a conventional panel, the avoided costs of a resulting service upgrade can be hefty [19]. Particularly for households receiving electrical service through underground wires, the avoided costs are likely to pay for the smart panel upgrade many times over.

To encourage electrification, policymakers should provide incentives to homeowners to reduce the costs of panel upgrades, especially for low- and moderate-income households. For example, the climate provisions of the 2021 budget reconciliation bill passed by the House of Representatives [20] included direct rebates of up to \$3,000 for this. The Senate should move quickly to pass this legislation with these measures intact. Utilities can also play a role, providing information on smart panels and incentives to defray the upfront cost premium when a customer applies for a service upgrade [21]. Further, the National Fire Protection Association's Committee on the National Electrical Code should modernize regulations on electrical panel sizing to clarify that smart panels allow extra load to be added to an existing electrical service. Finally, in cases where a service upgrade is unavoidable, utility regulators should reallocate subsidies for natural gas connections [22] to electrical service upgrades.

Our grid today is built for the worst-case scenario: the short, rare instances where households are using all of their machines at once. This is an inefficient use of electric infrastructure, and makes scaling our electric grid to support an increasingly electrified economy harder than it needs to be. Smart grid technologies like smart panels can maintain the necessary reliability and resiliency of the grid, while allowing us to scale our infrastructure more efficiently and cost-effectively.

Sam Calisch is the Head of Special Projects at Rewiring America, where he conducts research, writes, and occasionally dresses like a heat pump. He also is a founder of Channing Street Copper, a start-up broadening access to electrification by commercializing a retrofit-ready induction range. Previously, Sam was a Research Fellow at Lawrence Berkeley National Lab and has run projects with the National Science Foundation and Department of Energy. Sam completed his PhD at MIT and BA at Grinnell College.

Cora Wyent is a Research Associate at Rewiring America, where she is conducting research and analysis to enable rapid electrification of everything in the economy. She completed her PhD in Physics at Caltech, where she studied new materials for ultrathin solar cells and performed technoeconomic analysis of new photovoltaic and carbon capture technologies. Cora received her bachelor's degree in Physics from UNC Chapel Hill. She currently lives in Los Angeles with her wife and their cat.

Acknowledgement:

The authors would like to thank Joel Rosenberg, Steve Pantano, Ari Matusiak and Leah Stokes of Rewiring America for helping bring this piece together. Additionally, thanks to Kelsey Wallace, Chad Conway, Brad Davids, Arch Rao, Julia Sachs and Jan Overgoor of SPAN for access to data from a fleet of smart panels and helpful discussions of the role of smart panels in electrification.

Notes:

[1] Grid expansion and resilience is a huge topic – in this article we focus on technologies near the point of use, namely smart panels. Consider this to be part one of a series on the larger topic.

[2] In The [Rewiring America Handbook](#) (Saul Griffith, Sam Calisch and Laura Fraser, July 2020) and [Electrify](#) (Saul Griffith, MIT Press, 2021), the authors show how the U.S. economy can be run on roughly 45 Quads of energy per year. Over the 8,760 hours in the year, this amount of energy is equivalent to an average power of 1500GW. Arguing conservatively, we ignore the biofuels and other non-electric energy sources likely to be responsible for a portion of this total, and assume all of this energy is supplied by electricity. In contrast, [according to the EIA](#), today we deliver approximately 4.1 million GWh over the 8,760 hours of the year. This is equivalent to an average power of approximately 470 GW. Thus, in this nearly-completely electrified future scenario, we need to supply about 3.2 times as much electricity as we do today.

The IPCC also estimates the increase in electricity delivered, assuming the use of biofuels, carbon capture and sequestration, hydrogen, and significant behavior change for demand side mitigation. To achieve a likely 2°C temperature rise, approximately 200 to 225 EJ of electricity per year are required globally ([See AR6 WGIII Figure 3.23](#)). This represents an increase of approximately 2.2 to 2.5 times over today's levels.

In the IEA Net Zero scenario (see [Net Zero by 2050 - A Roadmap for the Global Energy Sector](#) Figure 3.9), the electricity demand is expected to double by 2050 in “advanced economies” like the U.S.

These estimates are based on a top-down energy transition model based on climate goals. In contrast, other studies use a bottom-up technology adoption model based on current trends. These studies generally find the increase to the amount of delivered electricity to be lower. For example, in NREL's [Electrification Futures Study](#), the “High” adoption scenario projects an increase in delivered electricity of roughly 160%. This scenario is based on “a combination of technology breakthroughs, policy support, and underlying societal and behavioral shifts that yield an electrification transition.” The rate of adoption is “impacted by a wide range of factors including economic trade-offs, consumer preference, and policies”.

[3] According to a [2016 NREL study](#), our collective rooftops represent about 1,118 GW of potential solar capacity. After subtracting the roughly 27GW of small scale solar currently installed (see [EIA Table 4.3. Existing capacity by energy source](#)), the difference is remarkably close to the additional capacity needed, even at the upper estimates of increased demand. However, after taking into account the economic feasibility of each installation, and the need to supply power to match demand, the amount likely to be deployed is likely less.

[4] Much of this skepticism is not based in fact, but there are legitimate concerns about ensuring adequate investment in the grid. In places where adoption of electrification has taken off and investments have not kept pace, there are signs of strain. For a good narrative description of such a scenario, see [Old Power Gear Is Slowing Use of Clean Energy and Electric Cars](#), Ivan Penn, [The New York Times](#). For quantitative analysis, see [Can Distribution Grid Infrastructure Accommodate Residential Electrification and Electric Vehicle Adoption in Northern California?](#), Anna Brockway, Duncan Callaway, and Salma Elmallah, June 2022.

[5] According to the EIA's [Table 7.2a Electricity Net Generation: Total \(All Sectors\)](#), in 1950, 334 GWh were delivered. By 1960, 759 GWh were delivered, a 227% increase. By 1970, 1,535 GWh were delivered, a 202 percent increase over 1960 and a 460 percent increase over 1950!

[6] Major national campaigns were used in this time to spread public awareness, including the [Live Better Electrically: The Gold Medallion Electric Home Campaign](#) by General Electric and Westinghouse.

This campaign extolled the virtues of electric appliances and featured then-actor Ronald Reagan as the main spokesperson.

[7] See Argonne National Lab's [Light Duty Electric Drive Vehicles Monthly Sales Updates](#) and the Air Conditioning, Heating, and Refrigeration Institute's [Central Air Conditioners and Air-Source Heat Pumps Sales Data](#).

[8] To date, these technologies have been referred to as the "smart grid", where information about grid conditions is passed alongside the electricity in order to increase resilience and efficiency. See [Grid Modernization and the Smart Grid | Department of Energy](#) and [Demand Response | Department of Energy](#).

[9] See FERC's [National Action Plan on Demand Response](#) for examples.

[10] The electrical panel (also known as breaker box, panelboard, distribution board, switch box, and probably more) is responsible for safely delivering electricity from the utility's power lines to your home's outlets and appliances. Electricity first travels from the power lines on the street through either underground or above-ground service wires. It passes through a second set of service entrance wires, through your meter, and then arrives at your electrical panel. The electrical panel splits the electricity into different circuits for the locations and appliances in your home. The utility owns the service wires and the meter, and the customer owns everything else: the service entrance wires, the electrical panel, and the wires that distribute electricity throughout the home.

[11] When installing a new circuit for such an appliance, an electrician sizes an electrical panel by calculating a given home's peak electricity usage, summing up how much electricity all of the appliances and loads would use if they were turned on at the same time. An example of an electrical load calculation worksheet is shown [here](#). A few example homes are shown on Redwood Energy's [Watt Diet Calculator](#), and Pecan Street's study [Addressing an Electrification Roadblock: Residential Electric Panel Capacity](#). A typical electrified 2000-square foot home might have approximately the following loads:

- Lighting = 6 kVA
- EV charger = 10 kVA
- Electric cooktop & oven = 10 kVA
- Electric dryer = 5 kVA
- Heat pump (no back-up heat) = 5 kVA
- Heat pump water heater = 5 kVA
- Dishwasher, microwave, washing machine, garbage disposal, 2 x other appliances = 1.5 kVA each

This sums to 50 kVA total. Per the National Electric Code (NEC), to size an electrical panel, we sum up 1) 100 percent of the first 10 kVA, then 40 percent of the remaining kVA, for lighting and appliance loads, and 3) all of the heating/cooling load (whichever is greater if separate appliances are used for heating and cooling). For this home, that yields $10 + 0.4 \times 35 + 5 = 29$ kVA, which is 121 A after dividing by 240V. With traditional electrical panels and no circuit-sharing devices, this home would need a 150 A or 200 A electrical panel. Having solar panels could further increase the necessary amperage.

[12] This figure is based on data from over 1,000 homes with smart panels provided by SPAN. Peak loads are evaluated as a maximum of current measurements taken every second through the main breaker, while averages are the total energy delivered through the main breaker divided by the time in operation. There is some regional variation in this ratio, with the “Very Cold” climate region having average values near 20, while “Mixed Humid” region had values of approximately 10. See [DOE Building America Climate Zone Guide](#) for climate zone definitions.

[13] The amp (short for ampere) is the unit of electrical current, or flow of electricity. Electrical panels are measured by how many amps they can provide. Older, smaller houses may have panels that can provide 60 or 100 amps, while newer, larger houses likely have 200 amp panels.

[14] This can be confusing, but in short, 80 amps is considered a safe, conservative, continuous load limit for a 100 amp panel. The National Electric Code rules for load sizing are complex (see [NFPA 70: National Electrical Code](#)) and not designed with active load management in mind. However, conductor sizes and overcurrent protection for feeders and services are specified so continuous loads are limited to 80 percent of the overcurrent limit (See 215.3 and 230.42(A)(1) of the NEC). Further, most standard circuit breakers themselves are only designed to sustain 80 percent of their nameplate ratings for an extended period of time (i.e., 80 percent of the number of amps that will cause the breaker to trip and disconnect the circuit). See [Clearing up Confusion over 80% vs. 100%-rated Circuit Breakers, Schneider Electric Blog](#). Even with continuous loads limited to 80 amps, startup surges will create brief spikes above this baseline. If the continuous load baseline were higher, these spikes would frequently trip the main breaker, cutting power to the house and inconveniencing the homeowner.

Finally, the house from which this data comes actually had a panel larger than 100 amps, but we use this threshold to illustrate the common case of electrification with this panel size.

[15] The majority of home electrical loads, like water heaters and HVAC equipment, operate cyclically, turning full-on for a period, and then full-off for a period, supplying the right amount of average power to keep the house comfy and the water hot. Because of this, under most conditions, such loads can be synchronized to avoid turning on at the same time without any noticeable interruption in service to the homeowner. Other loads (like electric vehicle charging) can be easily shifted within a window of time (e.g., when the car is plugged in) in order to avoid drawing too much electricity.

[16] Here “peak event” is defined as any instance where total load exceeds 80 amps.

[17] To our knowledge, there is no complete data on US-wide panel sizes. Three independent sources give us the 60 percent estimate. First, the [Addressing an Electrification Roadblock: Residential Electric Panel Capacity](#) study from Pecan Street looked at a sample of 263 Texas homes and extrapolated to the US, finding that 48 million single-family households (out of 86 million total single-family households) would likely need a panel upgrade in order to electrify. In their Texas sample, 60 percent of homes have electrical panels sized below 200A. Second, the [Service Upgrades for Electrification Retrofits Study Draft Report](#) estimates that 70 percent of California homes have at least 100A panels based on year of construction. (This overestimates the number of <200A panels because it includes those with larger panels, but underestimates because it excludes those who upgraded their panels to install air conditioning. As all new construction in CA must have 200A panels, we assume that the number with less than 200A panels is around 60 percent). Third, we can assume as a general rule of thumb that single-family homes 2500 square feet and over have at least 200A panels, and most homes that are less than 2500 square feet have less than 200A panels. According to the [Residential Energy Consumption Survey](#), about 70 percent of US homes are under 2500 square feet in size. This is certainly a rough estimate, and better data on electrical panel sizes across the US is needed.

[18] There are additional methods that allow households to electrify while avoiding electrical panel and service upgrades in some cases. Circuit-sharing plugs allow two colocated appliances that use a lot of electricity, like an EV charger and a clothes dryer in a garage, to share a plug and gracefully avoid turning on at the same time. Two examples of companies that sell circuit-sharing devices are [NeoCharge](#) and [Splitvolt](#). Smart breakers can also provide some of the functionality of a smart panel for individual circuits. Another option is use of a meter collar, such as [this one](#) from Siemens and ConnectDER, which installs between the existing electric meter and meter socket. In addition to avoiding upgrading the electric panel, these collars can monitor the total load and modulate the downstream circuit (such as an EV charger) to stay within the limits of the incoming service.

Alternatively, households can also select power-efficient appliances and lower amp EV chargers to keep their electrical needs under 100 amps. Several handy electricity budget calculators exist to help with this. For instance, Redwood Energy's [Watt Diet calculator](#) can help households and electricians size electrical panels, and select power-efficient appliances in order to avoid panel and service upgrades. For example, although 50-amp circuits are commonly used for EV charging, a 20-amp circuit can provide 100 miles of charge overnight, more than enough for most people to get to and from work each day. Power-efficient appliances are coming to the market, including 120-volt heat pump water heaters, 120-volt stovetops and ranges, and 120-volt ductless mini-split heat pumps, as well as lower-amp versions of those appliances.

[19] Electrical service upgrades can be lengthy and expensive, involving swapping out the wires that connect your house to the power lines on the street with larger ones. In some cases, it may also involve some other upstream upgrades, such as swapping out transformers and high voltage power lines. Because of the need for trained technicians and shutting off electricity to the lines, service upgrades can take upwards of six months, and can cost anywhere from \$2,000–\$30,000, without including the electrical panel upgrade. Though the utility typically covers a portion of the costs, even the costs that the utility covers will ultimately be distributed among ratepayers. If we assume a cost of \$5,000 per home for a service upgrade, the cost to upgrade electrical service on all homes in the U.S. would be roughly \$250 billion.

The total project costs can be broken into three categories: 1) the cost of the electrical panel, 2) the cost of the service line replacement, and 3) other related costs, such as replacing the pole and transformer. Within each of these categories, there are costs associated with labor, materials, and permits, and all are incorporated into the following cost estimates. The cost of the electrical panel is always the customer's responsibility, and can range from \$2,000–\$4,500. The cost of the service line replacement is supposed to be covered by a service extension allowance, which is in the range of \$2000–\$3000 and represents the average cost paid by the utility. Customers are responsible for any costs above that allowance. Any project that is not a simple above-ground line replacement (e.g. if service wires are underground) is likely to exceed the allowance, and can cost up to \$16,000. Replacing the pole and the transformer is the customer's responsibility if they are the only customer on the transformer, the utility's responsibility if there are three or more customers on the transformer, and split otherwise. A transformer replacement can cost \$6,000–\$8,000, and a pole replacement can cost \$9,000–\$11,000. In total, the cost to upgrade the electrical service (not including the electrical panel upgrade) can range from \$2,000 to upwards of \$30,000. See the [Service Upgrades for Electrification Retrofits Study Draft Report](#).

Beyond cost, the long timelines of service upgrades can be a deterrent for consumers considering electrification, and can often result in customers deciding instead to purchase new gas-powered appliances, locking in fossil fuel usage for decades.

[20] In the text passed by the House (see [117th Congress \(2021-2022\): Build Back Better Act](#)), electric service panels rebates are included in the High-Efficiency Electric Home Rebate program. In the Senate finance committee text (see [TITLE XII—COMMITTEE ON FINANCE](#)), electric panels are also included in the 25C residential energy property tax credit.

[21] It is important to note that the ideal time for a customer to install a smart panel is when they are already doing a panel upgrade, since there is typically no incremental installation cost, only a minor incremental hardware cost.

[22] For example, see [Revisiting California's natural gas hookup subsidies](#), Utility Dive.

CIRCUIT BREAKER:

Exporting oil and gas does not create energy independence, electrification does.

By Sam Calisch (Rewiring America)

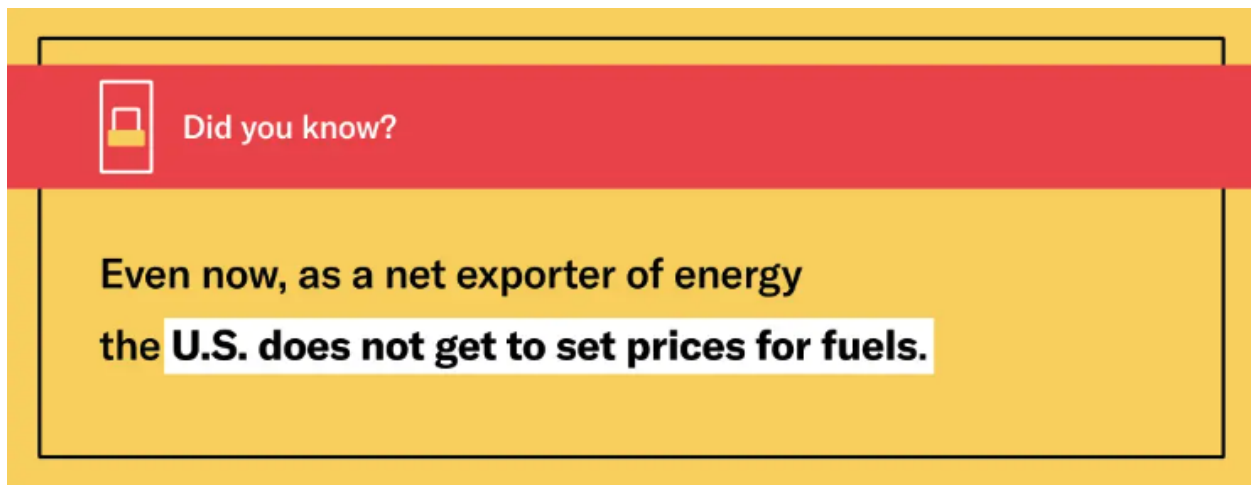
May 5, 2022

Focus points:

- Even though the U.S. now exports more oil and gas than it imports (often called “energy independence”), we remain very dependent on world energy markets, buying and selling fossil fuels at prices we don’t control.
- There are technical, economic, and political reasons for this, but the result is the same: global fossil fuel price volatility exposes everyday Americans to economic hardship, a fact laid bare by the 2022 invasion of Ukraine.
- There is, however, a path to true energy independence: full electrification powered by renewable energy. This not only results in low, stable energy prices, but also combats the existential threat of climate change.



In 2019, the U.S. became a net exporter of energy for the first time in nearly 70 years [1]. In other words, it sold more oil and gas to other countries than it bought from them. This shift was largely driven by the shale revolution, where hydraulic fracturing (“fracking”) and horizontal drilling enabled access to previously unreachable oil and gas deposits [2] and the adoption of liquefied natural gas (LNG) export facilities, which allowed gas to be shipped around the world just like oil [3].



Much has been said about how being a net exporter of energy establishes the U.S. as “energy independent,” theoretically making it immune to changes in supply and demand of energy across the world. As the argument goes, if geopolitical events upset global energy markets, the U.S. can keep energy affordable by using its own production to meet domestic demand [4].

This argument is flawed in several ways.

The first flaw is that fossil fuels are commodities traded on global markets and exposed to global prices. Because of this, even now, as a net exporter of energy, the U.S. does not get to set prices for fuels.



The destabilization of energy markets following the 2022 invasion of Ukraine by Russia has laid these forces bare.¹⁰

The price of gasoline, required to get Americans to work every day, has risen by 54 percent over the last year, representing an additional \$800 of annual spending for the average household.¹¹

These prices fluctuate based on global events, and the U.S. is forced to handle the resulting volatility.

Second, for technical reasons we cannot just use our own oil and gas exclusively. In the case of oil, this is because crude oil (what comes out of the ground) is not used directly; it must first be refined into gasoline, diesel, kerosene, distillates, and other products by selling crude oil to a vast network of refineries across the globe. Further, not all crude oil is the same. U.S. refineries are mostly set up to process “heavy” crude oils, but our domestically produced crude tends to be “light” [5]. Because of this, the U.S. imports a substantial amount of heavier crude oil to operate the domestic refinery fleet economically.

In the gas market, many regions of the country lack sufficient infrastructure to transport and store natural gas, and hence must rely on imports, typically liquefied natural gas (LNG), to meet demand. For instance, New England lacks any gas production or storage facilities, and is isolated from domestic LNG supply by Jones Act shipping restrictions [6]. Hence, when demand outstrips supply in the winter heating season, international LNG imports are the region’s only option to keep households’ gas furnaces and water heaters running [7]. Thus, despite being the

world's largest natural gas producer, the U.S. still must import significant quantities of natural gas [8].

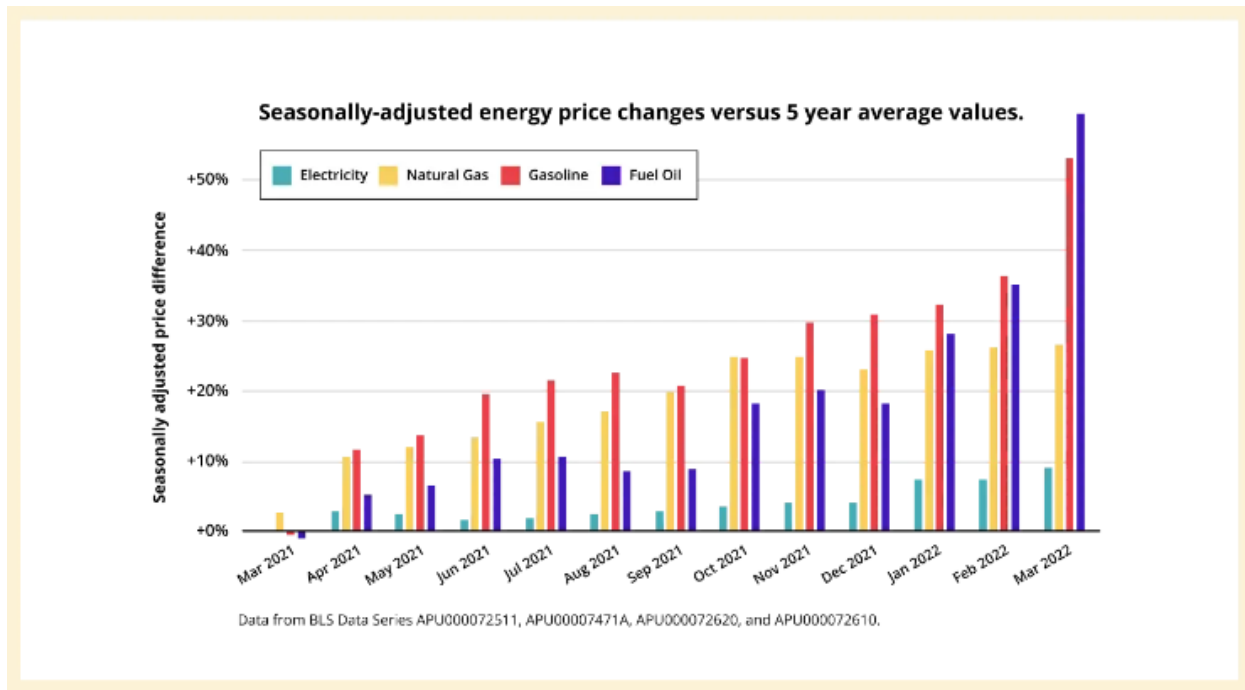


Figure 1: Seasonally-adjusted energy price changes versus 5 year average values. Data from BLS Data Series APU000072511, APU00007471A, APU000072620, and APU000072610.

The third flaw in the argument is that it ignores how volatility in the global price of fossil fuels hits everyday Americans. The households depending on gasoline-powered cars to get to work and gas furnaces to stay warm have no recourse when energy prices go up. The small businesses struggling to keep their doors open must pay their bills, even when they rise unexpectedly. Meanwhile fossil fuel companies rake in record profits as their products are suddenly more valuable, and those who depend on them will continue to pay, despite the high prices. In these times, the government steps in to set domestic and international policies to alleviate hardships on those affected [9]. This mechanism is yet another reason the U.S. is not “independent” from the global energy markets, despite being a net exporter.

The destabilization of energy markets following the 2022 invasion of Ukraine by Russia has laid these forces bare [10]. The price of gasoline, required to get

Americans to work every day, has risen by 54 percent over the last year, representing an additional \$800 of annual spending for the average household [11]. Prices of heating oil, used for space and water heating by over seven million American households [12], rose by 72 percent over the last year, representing an additional \$960 of annual spending for the average household [13].

Fortunately, there is a path to true American energy independence: electrification.

Using electricity is cheaper and less volatile than using fossil fuels. As an example, see Figure 1, showing price changes over the last year of common fuels compared to their five year average price [14]. As we have seen, prices for fossil fuels have risen rapidly over the past year, especially in 2022. In contrast, electricity prices have remained relatively low and stable, rising roughly three times less than even natural gas, the fossil fuel often touted as affordable [15]. Why is this?

First, electricity markets are inherently local, not global [16]. Today, the average distance between households and the nearest major electricity generation facility is just 5 miles [17]. If that electricity comes from a rooftop or community solar project, this distance is even less. Long distance transmission lines do move electricity around the U.S., but major international trade is not possible. In contrast to fossil fuels, dollars spent on electricity largely stay inside the U.S., if not within your community [18].

Second, the price of electricity produced by cheap renewables like wind and solar is inherently stable. Because the wind and sun are free, the cost of this renewable electricity is largely set by taking the upfront costs to build the solar or wind farm and simply spreading them out over the 20-30 year lifetime [19]. Without unpredictable fuel prices, wind and solar can provide stable, low cost electricity and protect consumers from energy price shocks. Today, the price of electricity still exhibits some volatility because fossil fuels are used to power a portion of the grid. This volatility is diluted, however, by the financed cost of power plant capital equipment, as well as the portion of electricity supplied by renewables. Over the past year, however, 17

states got the majority of their electricity from stable, clean sources [20]. As this number continues to grow, the price of electricity will become even more stable.

As we have seen, the notion that exporting oil and gas makes the U.S. energy independent is not true, and current trends make this clear. In contrast, electrification really is a path to true energy independence, combating not only the burden of rising fuel prices but also the worst effects of climate change. The U.S. should double down on clean energy technologies and electrification investments today. We have the technology we need today to be energy independent, and electrifying everything is the key.

Sam Calisch is the Head of Special Projects at Rewiring America, where he conducts research, writes, and occasionally dresses like a heat pump. He also is a founder of Channing Street Copper, a start-up broadening access to electrification by commercializing a retrofit-ready induction range. Previously, Sam was a Research Fellow at Lawrence Berkeley National Lab and has run projects with the National Science Foundation and Department of Energy. Sam completed his PhD at MIT and BA at Grinnell College.

Notes:

[1] In the 1950s, the U.S. imported only about 2 Quads of energy (quadrillion British thermal units), while exporting approximately the same amount. Both amounts were small compared to the roughly 30-40 Quads of energy that were produced and consumed domestically. Over the next 20 years, consumption approximately doubled, while production grew more slowly. As a result, imports grew by roughly ten times, while exports remained roughly the same. This state of being a net energy importer remained true until 2019, when the rapid rise in domestic production fueled by the shale revolution reached a point when exports surpassed imports. See the EIA's [Monthly Energy Review](#).

[2] Widespread use of fracking and horizontal drilling have increased access to previously-unreachable oil and gas formations, and are largely responsible for the dramatic rise in U.S. energy production in

the last ten years (See the EIA's [SEDS Data](#)). The use of these techniques has also had significant negative effects, including groundwater and soil contamination, methane pollution, fracking-induced earthquakes, and a host of public health risks. See [Natural Gas Operations From a Public Health Perspective](#), [Methane and the greenhouse-gas footprint of natural gas from shale formations](#), [Human health risk assessment of air emissions from development of unconventional natural gas resources](#). For a good discussion of the shale revolution and U.S. energy policy, see the IEA's [Energy Policies of IEA Countries: United States 2019 Review](#).

[3] Liquefied natural gas (LNG) is a way to ship gas in much the same way we ship oil. The key to this is cooling the gas down to -260 degrees Fahrenheit, at which point it becomes a liquid, and has a volume roughly 600 times smaller than when it was a gas at standard pressure and room temperature. This shrink is key to fitting enough gas on a ship to be economically feasible. Between 2015 and 2020, the amount of LNG exports from the U.S. increased by approximately ten times. Critically, this liquefaction process takes a good deal of energy – the EIA estimates that 15-18% of the gas transported as LNG is consumed by the process requirements. See [Natural gas explained: Liquefied natural gas](#), U.S. EIA and [Liquefied Natural Gas \(LNG\)](#), Office of Fossil Energy and Carbon Management, U.S. DOE

[4] The notion of energy independence largely dates to the 1970s, when the U.S. became a net oil importer, and an oil embargo was placed against the U.S. in retaliation for actions taken in the 1973 Arab-Israeli War. President Nixon created “Project Independence,” a plan to eliminate imports of foreign oil (a good historical timeline is given in [Energy Independence: A Short History](#)). The U.S. then passed the [Energy Policy and Conservation Act](#) (EPCA) in 1975, which created the Strategic Petroleum Reserve and the first fuel economy targets for automobiles. The EPCA also included the Crude Oil Export Ban, which eliminated nearly all exports of domestic oil.

In 2015, after 40 years in effect, the ban was repealed in the [Consolidated Appropriations Act of 2016](#). Despite this, after the ban was lifted U.S. oil imports remained largely unchanged. See the EIA's [US Imports of Crude Oil and Petroleum Products](#) for data, and the GAO's [Effects of the Repeal of the Crude Oil Export Ban](#) for discussion.

[5] The “heavy” and “light” designations refer to the oil density, as measured by API gravity, named after the American Petroleum Institute. A light oil has a high API gravity (>31), while heavy oils have low API gravity (<22). The shale formations associated with the increase in U.S. domestic production generally contain light crude oils (see the EIA's [Crude Oil and Lease Condensate Production by API Gravity](#), [Percentages of Total Imported Crude Oil by API Gravity](#), and [Today in Energy: August 23, 2019](#)). Another important parameter of crude oil is sulfur content. Low sulfur content oils are called “sweet”, while higher sulfur content is called “sour”.

[6] The Merchant Marine Act of 1920 (also known as the Jones Act) is a major U.S. statute pertaining to commercial maritime shipping, put in place after World War I to build the domestic shipping industry. The statute states that any ship moving goods from one domestic port to another must be built, owned, and operated by American citizens or permanent residents. A vessel meeting the requirements of the statute is often called Jones-Act-compliant.

There are currently no Jones-Act-compliant LNG tankers capable of transporting bulk quantities of LNG. According to the CATO Institute, as of 2019 there were only two compliant barges, but barges differ from tankers in that they carry significantly less LNG (40-70x less in this case), and are meant for refueling other vessels running on LNG rather than transporting large quantities of LNG to port. Shell and Crowley recently announced building the largest Jones-Act-compliant LNG barge to date, set to be placed in service in 2024, but its capacity is still about 15x less than a common tanker size, and is slated to be used for refueling other ships. The lack of compliant tanker vessels is largely driven by the high cost of building in American shipyards. Industry experts estimate building a Jones-Act compliant LNG tanker would cost approximately \$500 million, about three times more than building the same vessel in an Asian shipyard. The Jones Act has accumulated considerable political support (including Senator Mitch McConnell), and any changes to it would face a considerable uphill battle.

[7] The EIA's New England Dashboard contains detailed information on the region's natural gas infrastructure, including LNG terminals. The Natural Gas Weekly Update contains data on overall U.S. deliveries by LNG tanker and pipeline, as well as the state of national storage facilities. The Underground Natural Gas Working Storage Capacity reports that natural gas storage capacity was essentially unchanged during 2020. The 2021 article, The Role of Liquefied Natural Gas in the US Gas Market, contains a discussion of LNG and the constraints in New England.

[8] Data on natural gas production by country are available from the EIA here. Data on U.S. natural gas import quantities are available from the EIA here.

[9] A poignant example is the recent and unprecedented release of one million additional barrels per day from the U.S. strategic reserve. See FACT SHEET: President Biden's Plan to Respond to Putin's Price Hike at the Pump | The White House.

[10] The dramatic rise in fossil fuel prices during the last six months are the combination of two major events. First, extreme weather and supply chain shortages disrupted production during the summer of 2021. This led to historically low levels of gas in storage reservoirs leading into the winter. (See the IEA's What is behind soaring energy prices and what happens next? and Rewiring America's Energy Bill Security for American Households Through Electrification). Then, in February 2022, Russia's invasion of Ukraine sent prices still higher, as many countries moved to stop importing oil from Russia.

[11] Gasoline price data is available from the Bureau of Labor Statistics (BLS) as series [APU00007471A](#). Annual household spending on gasoline (\$1,447) is available in the [BLS Consumer Expenditure Survey](#). For the lowest income decile, over 11% of pretax income goes to gasoline. With price increases, this rises to 18%. See [Table 1110. Deciles of income before taxes: Annual expenditure means, shares, standard errors, and coefficients of variation, Consumer Expenditure Surveys, 2020](#).

[12] The U.S. Census Bureau's [American Housing Survey](#) finds that approximately 7.3 million households use fuel oil for space or water heating, and that 5.7 million of these use it as their primary fuel. The EIA estimates more conservatively; according to the March 2022 [Short Term Energy Outlook Table WF01](#), 5.3 million households use fuel oil as their main heating fuel. Together these households consume approximately 3 billion gallons per year of fuel oil for residential space and water heating, according to the EIA's [Fuel Oil and Kerosene Sales Report](#). This is the highest consumption of distillate oil (the class of products including diesel and fuel oil) after use on roads and farms.

[13] Fuel oil price data is available from the Bureau of Labor Statistics (BLS) as series [APU000072511](#). Annual household spending on fuel oil (\$1,328) is available in the Energy Information Administration's [Short Term Energy Outlook Table WF01](#).

[14] Data from BLS Data Series [APU000072511](#), [APU00007471A](#), [APU000072620](#), and [APU000072610](#). Propane prices are not included as a series by the BLS, but are available from the EIA [here](#), though only for six months of the year.

[15] Clearly, a large number of electric power plants run on fossil fuels, and hence are impacted by global markets, but this only represents a small component of the price seen by the end consumer, and hence the volatility is reduced.

[16] Of the annual U.S. electricity demand, just 1% is imported, almost exclusively from Canada to states just across the border. The EIA [International Electricity data](#) contains year-over-year electricity imports, showing the U.S. imports approximately 60 billion kWh per year, almost exclusively from Canada.

[17] This value is calculated based on the EIA's location data for all generating facilities in the U.S., available from the EIA's [Form EIA-860 detailed data with previous form data \(EIA-860A/860B\)](#) and visualized in the [Electricity Data Browser](#). For every census tract in the U.S., we calculate the distance from the tract centroid to the closest generating facility, and then compute a population-weighted average over all census tracts using data from the Census Bureau's [Population and Housing Unit Estimates Datasets](#).

[18] For a discussion of where money spent on gasoline goes, see the Union of Concerned Scientists' [Where Your Gas Money Goes](#) and the EIA's [Gasoline Pump Components History](#).

Critics of electrification may object that dollars spent on capital upgrades like solar and electric vehicles are destined for overseas because the panels and batteries are manufactured abroad. These hardware costs, however, are only a small portion of the cost of these goods. For instance, according to NREL's [US Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021](#), panels were just 13% of the cost of a residential photovoltaic system. The largest portions of the remainder are domestic expenditures like sales and marketing, installer profit and overhead, and various balance-of-system components. In the case of EVs, according to the International Council on Clean Transportation's [Update on electric vehicle costs in the United States through 2030](#), battery costs are approximately one-third of vehicle costs.

[19] This is called the "levelized cost of electricity" (LCOE). The financial management firm Lazard [regularly publishes its data](#) on LCOE, and [NREL regularly publishes](#) up-to-date analysis. Besides the upfront capital costs of a solar or wind farm, there are additional operations and maintenance (O&M) costs. These have very minor impact on the price of renewable electricity because they make up just 1.5% of the solar LCOE according to [NREL's 2021 Solar Benchmark](#) and 4% of wind LCOE according to [NREL's 2020 Cost of Wind Energy Review](#). Further, these costs themselves are quite stable, as they consist of line items like regular solar panel cleaning, vegetation trimming, inspection, property taxes, and insurance payments.

[20] Monthly net electricity generation by source by state is available from the EIA [here](#). The 17 states with more than half of their generation from clean sources from 2021 to 2022 are CA, IA, ID, IL, KS, ME, MN, MT, NH, NJ, NY, OR, SC, SD, TN, VT, WA. Further, 33 states obtained over a third of their generation from clean sources.

Driving Cleaner

Electric Cars and Pickups Beat Gasoline on Lifetime Global Warming Emissions



[Union of
Concerned Scientists

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David Reichmuth

Jessica Dunn

Don Anair

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David Reichmuth is a senior engineer in the Clean Transportation Program.
Jessica Dunn is a senior analyst in the program. **Don Anair** is deputy director and research director of the program.

Designed by: Tyler Kemp-Benedict, www.tylerkb.com

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This report is available online at www.ucsusa.org/resources/driving-cleaner.

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with people across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

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[EXECUTIVE SUMMARY

To reduce both climate-changing emissions and exposure to air pollution, the United States must greatly reduce tailpipe emissions from cars and trucks. This makes the transition to electric vehicles (EVs) vital to meeting targets for both climate and public health. Using fully electric vehicles in place of conventional gasoline- and diesel-powered vehicles enables the complete elimination of tailpipe emissions.

While electric vehicles can eliminate tailpipe emissions, the *total* emissions from their use include emissions from two other sources: the electricity used to recharge EVs and the processes and materials used to manufacture them. Thus, the value of switching from gasoline and diesel cars and trucks to EVs will increase further as the electricity grid and manufacturing become cleaner.

Global Warming Emissions from Driving Electric Vehicles

To assess the total global warming emissions from charging electric vehicles, the Union of Concerned Scientists (UCS) addresses *all* contributions from electricity production. These include:

- Emissions that result from raw-material extraction, such as coal mining and natural gas drilling;
- Emissions from delivering these fuels to power plants;
- Emissions from burning those fuels in power plants to generate electricity;
- Electricity losses that occur during distribution from power plants to the point where the electric vehicle is plugged in; and
- The efficiency of the vehicle in recharging and using electricity.

Similarly, our assessment of the global warming emissions from comparable gasoline and diesel vehicles addresses emissions that result from:

- Oil extraction at the well;
- Transporting crude oil to refineries;

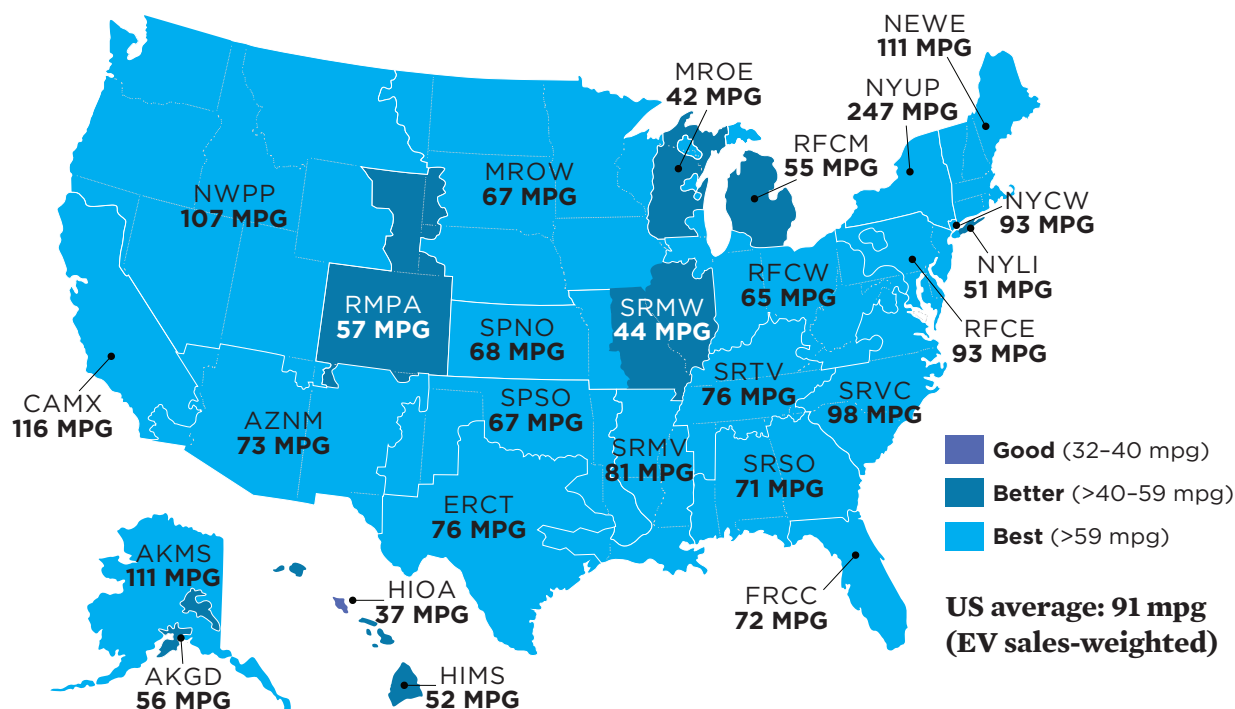
- Refining oil into gasoline;
- Delivering fuel to gas stations; and
- Combusting fuel in the vehicle's engine.

Because of differences in electricity generation across the United States, the emissions produced from driving the average EV vary depending on where the vehicle is driven (Figure ES-1, p. 2). Considering the location of EV sales to date, the UCS assessment finds that:

- Everywhere in the United States, driving the *average* EV results in lower emissions than the *average* new gasoline vehicle.
- Over 90 percent of people in the United States live in regions where driving the *average* EV produces lower emissions than the *most efficient* gasoline vehicle on the market today (59 miles per gallon).
- Driving the average EV in the United States produces global warming emissions equivalent to those emitted by a gasoline car getting 91 miles per gallon.
- Driving the *most efficient* EV produces lower emissions than the *most efficient* gasoline car where 97 percent of the population lives—in other words, virtually everywhere in the United States.
- Everywhere in the United States, the emissions from driving an EV pickup truck are lower than those for the average new gasoline or diesel pickup truck.

While driving the average EV yields significant emissions savings, the more efficient the EV, the greater the benefits of switching from gasoline to electricity. For example, the emissions from driving a 2021 Tesla Model 3 Standard Range Plus in California equal those of a gasoline car getting 152 miles per gallon. The Tesla's global warming emissions are a fifth of those of the average new gasoline car and over 60 percent less than even the most efficient gasoline car on the market.

FIGURE ES-1. Driving Emissions: The Miles per Gallon Equivalent of the Average EV



The average EV is considerably cleaner to drive than the average new gasoline vehicle—and in some areas, much cleaner. For example, in upstate New York (NYUP), the emissions of the average EV compare with those of a gasoline-powered vehicle achieving 247 miles per gallon. Based on where EVs have been sold in the United States, driving on electricity produces emissions equal to those of a gasoline car getting 91 miles per gallon.

Note: Acronyms refer to electricity grid regions as defined by eGRID (EPA 2022a).

Global Warming Emissions from Manufacturing Electric Vehicles

Manufacturing an EV results in more global warming emissions than manufacturing a comparable gasoline vehicle. This is chiefly due to the energy and materials required to produce an EV's battery. However, most of the global warming emissions over the lifespan of a vehicle occur during its use, so the reductions from driving an EV more than offset the higher manufacturing emissions. When comparing the average gasoline sedan (32 mpg) to the average-efficiency EV with a 300-mile-range battery, the EV reduces total lifetime emissions 52 percent. An EV pickup truck reduces lifetime emissions 57 percent compared with the average gasoline pickup (Figure ES-2).

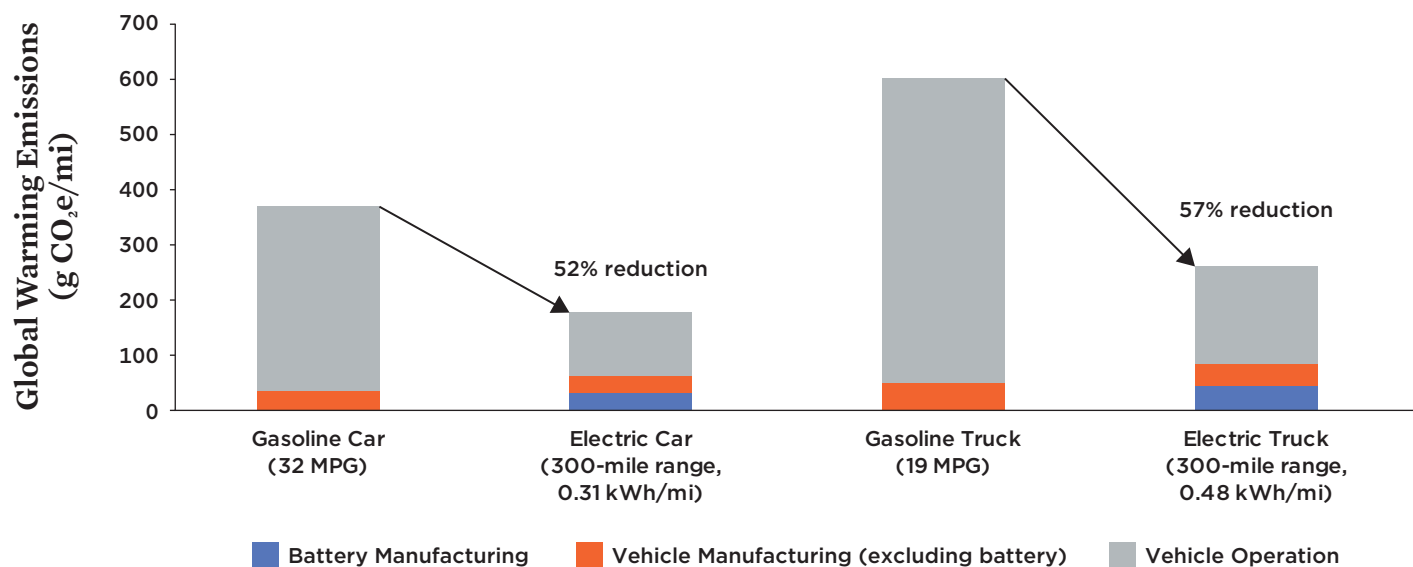
Another way to understand how emissions savings from driving an EV offset additional manufacturing emissions is to consider the breakeven point: how far (or how long) an EV needs to drive for the savings to match the initial emissions "debt." This breakeven point varies depending on regional electricity emissions. Based on where the US population lives, the mean breakeven point for an electric car with a 300-mile range

compared with the average new gasoline sedan is 21,300 miles of driving, or 22 months based on average annual driving. Break-even occurs more quickly, after about 17,500 miles (17 months), when comparing an electric truck (300-mile range) with the average new gasoline pickup truck.

Both EV cars and trucks are much cleaner than their gasoline counterparts, but electric trucks are responsible for more global warming emissions than electric cars simply because

Most of the global warming emissions over the lifespan of a vehicle occur during its use, so the reductions from driving an EV more than offset the higher emissions from manufacturing.

FIGURE ES-2. Life Cycle Global Warming Emissions, EVs vs. Gasoline Cars and Trucks



Life cycle global warming emissions are significantly lower for EVs than for gasoline cars or trucks when considering manufacturing and usage, despite higher battery-manufacturing emissions for the EV.

Note: Emissions are measured in grams of carbon dioxide-equivalent per mile, averaged over the life of the vehicle.

trucks are larger and heavier. Choosing the most efficient EV that meets mobility needs will minimize overall pollution. If a sedan meets a driver's needs, that would be a better choice for the environment than a full-size SUV or a pickup.

The impacts of manufacturing EVs, including their batteries, extend beyond global warming emissions. Manufacturing processes and the sourcing of battery and other materials also affect water and air quality. Also, processes and sourcing can raise concerns over human rights and the ethical issues involved in mining and refining raw materials. This makes it essential to reduce the amount of raw materials needed to make EVs. In particular, reuse, remanufacturing, and recovery of materials from used batteries will help reduce these impacts.

Recommendations

To maximize emissions reductions and minimize negative manufacturing impacts, UCS recommends accelerating the transition to lower-emissions transportation through cleaner sources of electricity, improved vehicle manufacturing, and more efficient vehicles.

- Policymakers at all levels of government should adopt and strengthen policies and programs for increasing energy efficiency and deploying renewable energy. Reducing the emissions from generating electricity can reduce the emissions from driving and manufacturing EVs. Policy options include establishing renewable electricity standards,

energy-efficiency resource standards, and incentives or mandates to improve grid operation, transmission, and resource planning.

- Governments and the private sector should invest more in research on both decreasing the global warming emissions associated with making EV batteries and improving the processes for recycling or reusing batteries.
- Policies should promote material circularity, in which materials reenter the supply chain when their use in the original product ends. Circularity includes encouraging materials recovery when a battery reaches the end of its life and using recovered materials in manufacturing. Offsetting the use of virgin materials can decrease the environmental and social impacts associated with mining.
- EV manufacturers should be responsible for sourcing materials ethically and sustainably throughout all steps in the supply chain. This means that their emissions and material sourcing must be transparent to the public and regulators.
- Public policies should ensure that manufacturers produce energy-efficient EVs. Policies also should encourage vehicle buyers to purchase the most efficient EVs that meet their mobility needs. The more efficient an EV, the smaller battery it needs to achieve a desired range capability, thereby reducing emissions from both driving and manufacturing.

- Policies, including funding, should support transportation options—including transit, shared mobility, and walking and biking infrastructure—that decrease the need for individual car ownership and limit the overall emissions from vehicle manufacturing and use.
- Vehicle incentives and infrastructure deployment should enable drivers across incomes and geographies to access EVs. To maximize the benefits of EVs, all drivers should be able to switch from gasoline and diesel vehicles.

Switching from conventional vehicles to electric vehicles reduces carbon emissions and smog-forming air pollution. To maximize these reductions, we must accelerate the adoption of EVs and transition to renewable electricity as quickly as possible. These dual transitions are a necessary part of putting the United States on a trajectory toward net-zero climate emissions by midcentury.

[To maximize reductions in carbon emissions and smog-forming pollution, we must accelerate the adoption of EVs and transition to renewable electricity as quickly as possible.]

[CHAPTER 1

Introduction

To reduce both climate-changing emissions¹ and exposure to air pollution, we must greatly reduce tailpipe emissions from cars and trucks. Using fully electric vehicles (also known as battery-electric vehicles, or BEVs) in place of conventional gasoline- and diesel-powered vehicles would completely eliminate tailpipe emissions from using cars and trucks. For this reason, the transition to BEVs is vital to meeting both public health and climate targets.

However, the total emissions from using an EV depend not only on tailpipe emissions but also on the source of the electricity used to recharge the vehicle and on the processes for manufacturing it. Thus, the value of switching from conventional gasoline and diesel cars and trucks to EVs will be even greater as the electricity grid and manufacturing become cleaner. This makes the transition to EVs even more central to any plan to achieve deep emissions reductions and avoid the worst impacts of climate change (Baek et al. 2021).

UCS first investigated the life cycle emissions of EVs a decade ago. Since then, the net benefit of driving an EV instead of a gasoline-powered vehicle has grown significantly. *State of Charge*, our 2012 examination, found that in every region driving the average new BEV produced lower global warming emissions than driving the average new gasoline car (Anair and Mahmasani 2012). However, at that time, only 46 percent of people lived where driving an electric vehicle had emissions lower than those of a 50 mpg gasoline car, the Toyota Prius hybrid, then the most fuel-efficient such car in the US market. In 2015, *Cleaner Cars from Cradle to Grave* updated the estimates: about two-thirds of the US population lived in areas where driving an electric car produced lower emissions than a 50 mpg gasoline car (Nealer, Reichmuth, and Anair 2015).

Since then, EV-related emissions have declined in many parts of the country, primarily because of changes to electricity generation. The nation's electricity generation has gotten cleaner: coal-fired generation has declined significantly, while electricity generation from wind and solar energy has increased. In the current UCS analysis, over 90 percent of the US population lives where driving the average all-electric car has

emissions lower than the most efficient gasoline vehicle now on the market, the Hyundai Ioniq Blue, a hybrid rated at 59 miles per gallon.

However, we must also consider the global warming emissions from a vehicle's overall life cycle, taking into account production, operation, and end-of-life emissions. The manufacture of EV batteries is of particular concern, and emissions also can be associated with battery disposal, recycling, and remanufacturing.

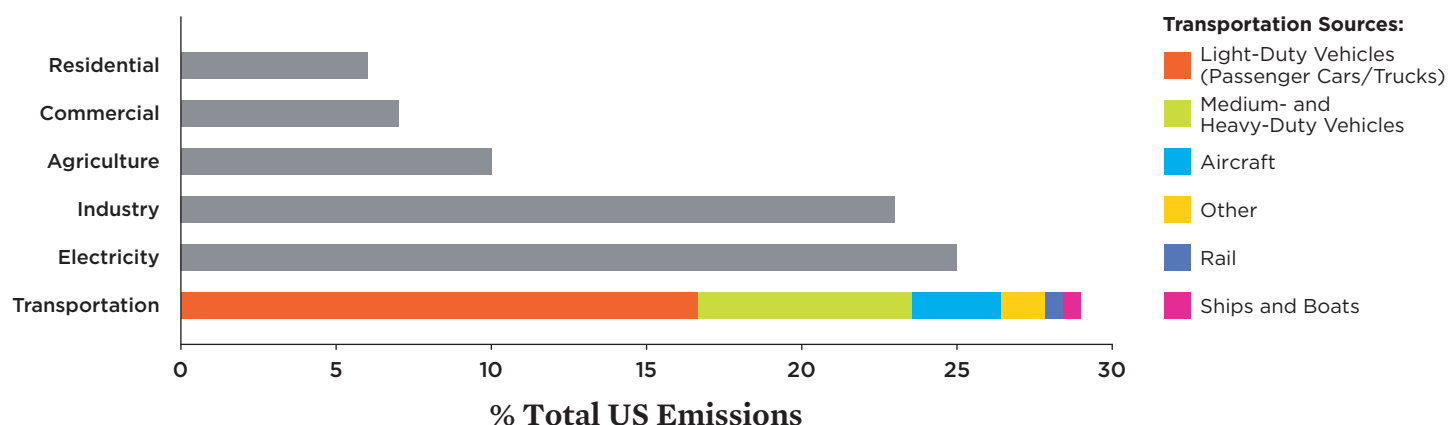
Like our 2015 report, this report compares battery-electric cars and trucks with gasoline cars and trucks by examining the global warming emissions from driving *and* manufacturing the vehicles and over their life cycles. Toward that end, *Driving Cleaner*, this up-to-date assessment of the carbon footprints of BEVs, takes into account the latest information about electricity generation and manufacturing processes.

Driving Cleaner addresses two key questions:

- **What are the global warming emissions from operating a fully electric vehicle on today's electricity grid?** Using the most recent electricity emissions data from the US Environmental Protection Agency (EPA), we estimated the miles-per-gallon rating a gasoline-powered vehicle would need in order to equal the emissions of a comparable EV charged on regional electricity grids.
- **What is the effect of manufacturing a BEV on its total global warming emissions?** Using Argonne National Laboratory's latest model of vehicle manufacturing emissions, we analyzed the global warming emissions of vehicle and battery manufacturing, focusing on long-range battery-electric cars and pickup trucks. We compared these with the emissions from manufacturing and using comparable gasoline vehicles.

In addition, *Driving Cleaner* looks briefly at the next stage: the environmental and global warming emissions consequences of what may be done with the EV battery after it has finished its useful life.

FIGURE 1. US Global Warming Emissions by Sector, 2019



Transportation is the largest source of human-caused global warming emissions in the United States. Passenger cars and trucks (light-duty vehicles) are responsible for over half of the global warming emissions within the transportation sector.

SOURCE: EPA 2021A.

It is important to note our focus on the benefits of vehicle electrification regarding global warming emissions from transportation. There are other potential benefits from the manufacture and use of electric vehicles in place of gasoline vehicles. For example, EVs have the potential to significantly reduce air pollution from passenger cars and trucks (CARB 2022), and they can reduce the need for oil extraction and refining. The sourcing of battery materials and EV manufacturing can affect water and air quality, as well as raise concerns over human rights and the ethical sourcing of materials.

Importance of Reducing Transportation Emissions

Transportation is the sector of the US economy producing the most global warming emissions, responsible for over one-quarter of total emissions arising from the activities of humans (Figure 1). Within transportation, light-duty vehicles (passenger cars, SUVs, and pickup trucks) are responsible for most climate-changing emissions. While it is important to reduce emissions from all sectors and sources as much and as quickly as possible, addressing the harmful emissions associated with passenger vehicles presents an immediate opportunity to reduce emissions significantly. Also, while some parts of the transportation sector, such as ocean-going vessels, may present a greater challenge as we seek to reduce air and climate pollution, electrification is a proven technology for curbing harmful emissions from cars and trucks.

Electrification Can Significantly Reduce Global Warming Emissions

Due to several factors, switching from gasoline- or diesel-powered engines to electric motors significantly reduces total global warming emissions:

- While gasoline and diesel fuels are derived mainly from a fossil fuel (crude oil), electricity can be generated from low- and zero-carbon resources like hydroelectricity, wind, and solar power.
- Electric-drive vehicles are more efficient than those powered by internal combustion engines.
- Electric vehicles lose no energy from idling, and there is no significant waste heat.
- The regenerative braking systems in EVs recapture the energy that conventional vehicles lose to friction when braking.

[CHAPTER 2

EV Savings Compared with a Gasoline Vehicle

In comparing the global warming emissions of BEVs with those of gasoline vehicles, UCS takes a “well-to-wheels” approach that accounts for the complete fuel cycle for both types of vehicle.

While BEVs have no tailpipe emissions, determining the net emissions benefit requires considering the total emissions from all steps in refueling both BEVs and conventional gasoline vehicles. To quantify this benefit, our well-to-wheels analysis considers not only tailpipe emissions but also the emissions from the steps required to produce gasoline and electricity, starting with primary energy sources like crude oil, coal, and natural gas.

To assess the global warming emissions from charging EVs, we include all contributions from electricity production:

- Emissions that result from raw-material extraction, such as coal mining and natural gas drilling;
- Emissions from delivering these fuels to power plants;
- Emissions from burning those fuels in power plants to generate electricity;
- Electricity losses that occur during distribution from power plants to the point where the electric vehicle is plugged in; and
- The efficiency of vehicles in recharging and using electricity.

To assess the global warming emissions from comparable gasoline vehicles, we address emissions that result from:

- Oil extraction at the well;
- Transporting crude oil to refineries;
- Refining oil into gasoline;
- Delivering fuel to gas stations; and
- Combusting fuel in the vehicle’s engine.

See Appendix A for a discussion of the methodology.

Standardizing the Units of Comparison

The concept of miles per gallon (mpg), the number of miles a car travels on one gallon of gasoline, is familiar. The higher a vehicle’s mpg (the higher its efficiency), the less fuel it burns and the lower its level of global warming emissions. To compare the emissions of an EV easily with those of a gasoline vehicle, we use an equivalency measure, calculating how many miles per gallon a gasoline-powered vehicle would need to achieve in order to match the global warming emissions of an EV.

The first step in this process is calculating the global warming emissions that result from generating the electricity needed to charge an EV. Then we convert this estimate into a gasoline miles-per-gallon equivalent—an MPG_{ghg} , where ghg stands for greenhouse gas (i.e., global warming) emissions. If an EV has an MPG_{ghg} value equal to the miles per gallon of a gasoline-powered vehicle, both vehicles would produce the same amount of global warming pollution for each mile traveled. If the MPG_{ghg} of an EV is twice that of a gasoline vehicle mpg, the emissions from driving the EV would be half those produced from driving the gasoline vehicle.

When estimating emissions from charging an EV in a particular region of the United States, we use *average emissions*: these are emissions averaged over the full mix of the region’s electricity sources. An alternative approach would be to consider only *marginal emissions*: emissions from the power plants that operate to meet new electricity demand on the grid. Our analysis uses average generation because it can be calculated from historical generation data without making assumptions about such factors as charging behavior (e.g., time of day) or the response of electricity generation units to an increase in demand.

It is important to consider that these results are from utility-scale electricity generation. They do not reflect generation from rooftop solar or other types of residential generation. In addition, individual utilities and customers within a region may have access to electricity with emissions that differ from the regional average.

Appendix B discusses the issue of average and marginal emissions further.

Rating the Regions

To further help consumers evaluate the global warming benefits of driving an EV in different parts of the United States, we rate areas as Good, Better, or Best to characterize the emissions benefit of switching from gasoline to electricity (Table 1).

- **Good:** EVs are equal to or better than the *average* conventional gasoline sedan (32 to 40 MPG_{ghg}). That is, driving an average-efficiency EV in these regions results in global warming emissions equivalent to gasoline vehicles with a combined city/highway fuel economy rating of 32 to 40 mpg. This level is better than that of the average new gasoline sedan (32 mpg) on the market today (EPA 2021b).
- **Better:** These regions correspond to the *most efficient* gasoline-only (non-plug-in) hybrids (>40 to 59 MPG_{ghg}). The most efficient gasoline hybrid currently available in the United States is the Hyundai Ioniq Blue, rated at 59 mpg.
- **Best:** Driving a typical EV in these regions is equivalent to gasoline-powered vehicles with a combined city/highway fuel economy of more than 59 mpg. In these regions, driving the *average-efficiency* EV produces lower emissions than the *most efficient* gasoline-only hybrid car.

The Average EV: Cleaner Than the Average Gasoline Vehicle

Because of differences in electricity generation, the emissions produced while driving the average EV in the United States vary depending on where the driving takes place (Figure 2a, p. 9).² Everywhere in the country, driving the average EV results in lower emissions than the average new gasoline vehicle. Over 90 percent of the people in the country live in places where driving the average EV has a higher MPG_{ghg}, and thus produces lower emissions, than the most efficient gasoline vehicle (59 mpg).

In some parts of the country, driving the average new EV will produce a little as one-eighth to one-quarter of the emissions from the average new gasoline car. For example, the average EV driven in upstate New York has emissions equal to a (hypothetical) 247 mpg gasoline car. In California, a gasoline car would need to get 116 miles per gallon to have emissions levels

TABLE 1. EV Global Warming Emissions Scale

	EV Driving Global Warming Pollution Equivalent (MPG _{ghg})		The Meaning for Global Warming Emissions
	car	truck	
Good	32–40	19–26	EVs are comparable to an above-average-efficiency gasoline model.
Better	> 40–59	> 26–37	EVs are comparable to the most efficient gasoline hybrid models available.
Best	> 59	> 37	EVs outperform the most efficient gasoline hybrid model available.

as good as those of the average EV. Based on where EVs have been sold in the United States, driving on electricity on average produces emissions equal to a 91 mpg gasoline car.³

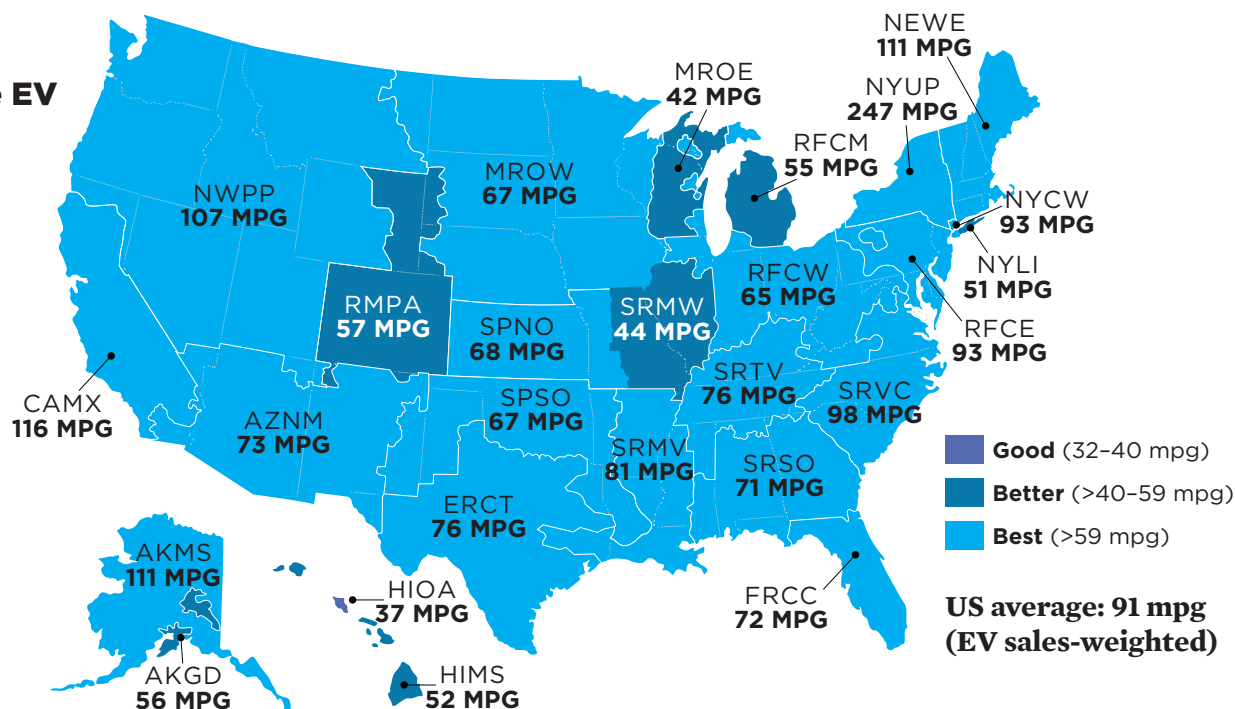
To Maximize Emissions Reductions, Choose a More Efficient EV

Driving the average EV yields significant emissions reductions from switching fuels; using the most efficient EV maximizes those emissions reductions. Driving the most efficient EV means lower emissions than the most efficient gasoline car for virtually everyone in the United States, with 97 percent of the population living in these areas (Figure 2b, p. 9). For example, driving the 2021 Tesla Model 3 Standard Range Plus, which consumes 0.24 kilowatt-hour (kWh) of electricity per mile, in California has emissions equal to a 152 mpg gasoline car. In other words, that Tesla produces one-fifth of the global warming emissions of the average new gasoline car and over 60 percent less than even the most efficient gasoline car. In upstate New York, the emissions from driving an EV can be as low as one-tenth those of an average new gasoline car. Based on where EVs have been sold over the last six years, the most efficient EV would have global warming emissions equivalent to driving a 119 mpg gasoline car.

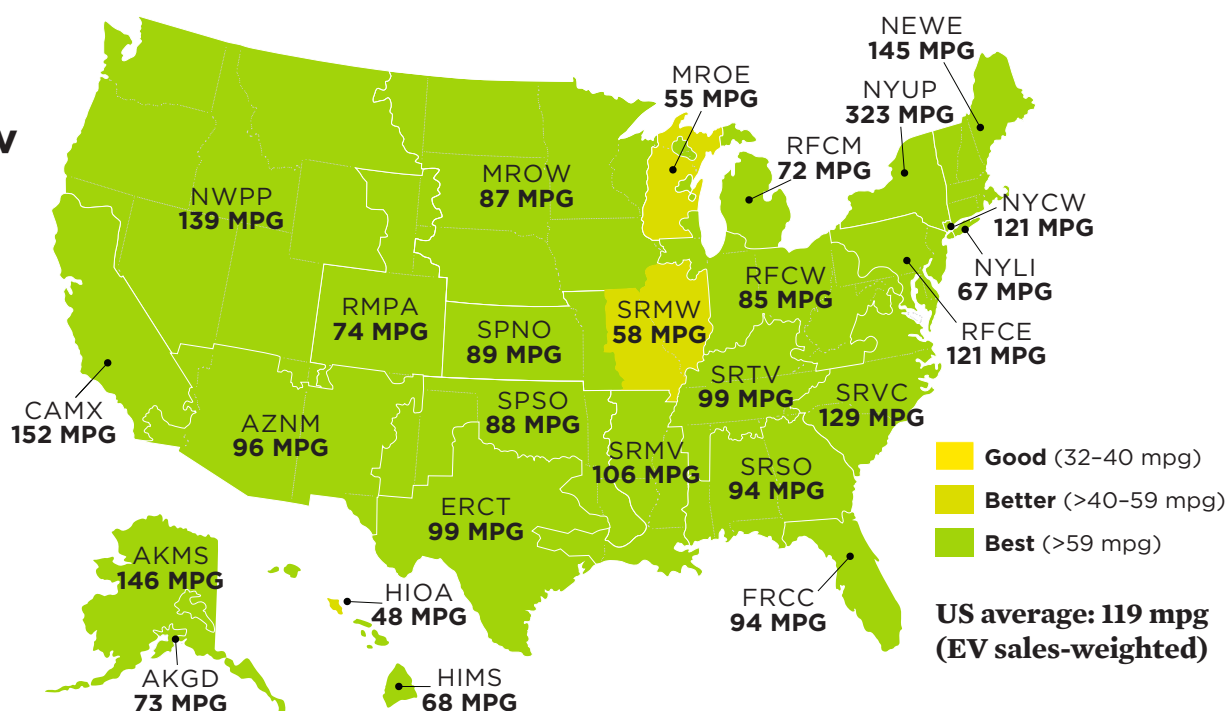
Based on where EVs have been sold in the United States, driving on electricity on average produces emissions equal to a gasoline car getting 91 miles per gallon.

FIGURE 2. Comparing Emissions: Driving an EV as a Gasoline MPG Equivalent, 2020

a. Average EV



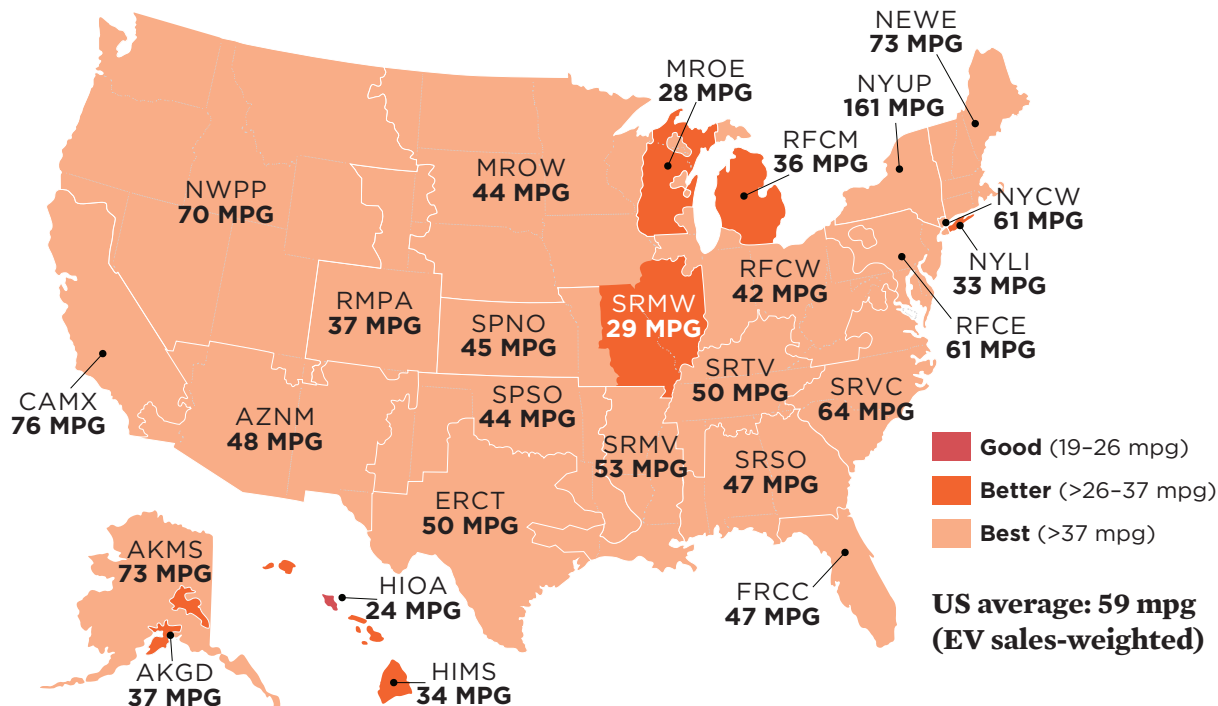
b. Most Efficient EV



The average EV is considerably cleaner to drive than the average new gasoline vehicle—and in some areas, much cleaner. For example, in upstate New York (NYUP), the emissions of the average EV compare with those of a gasoline-powered vehicle achieving 247 miles per gallon. Driving the most efficient EVs results in even lower emissions. For example, driving the 2021 Tesla Model 3 Standard Range Plus in upstate New York is equivalent to driving a gasoline vehicle achieving 323 miles per gallon.

Note: Acronyms refer to electricity grid regions as defined by eGRID (EPA 2022a).

FIGURE 3. Comparing Emissions: Driving the Average EV Pickup Truck as a Gasoline MPG Equivalent, 2020



Driving an electric pickup truck produces lower emissions than the most efficient gasoline model in most of the United States. For example, recharging and driving the Rivian or Ford F-150 Lightning pickup in California has the emissions impact of a hypothetical 76 mpg gasoline truck. Overall, based on where EVs have been sold, EV pickups would have emissions equal to a 59 mpg gasoline truck.

Note: Acronyms refer to electricity grid regions as defined by eGRID (EPA 2022a).

Even Less-Efficient EVs Can Lower Transportation Emissions

While many early EV models were sedans or small hatchbacks, manufacturers now offer more options, including not only fully electric SUVs but also pickup trucks such as the Rivian R1T or Ford F-150 Lightning, both of which have an efficiency of 0.48 kWh/mi (DOE 2022a). Larger, heavier vehicles like SUVs and pickups are inherently less efficient than sedans and smaller hatchbacks, whether powered by gasoline or electricity. Even so, electrification of the larger vehicles can lower global warming emissions if they displace inefficient gasoline and diesel SUVs and pickup trucks, which produce more emissions than electric cars. Consumers should choose the most efficient vehicle that meets their needs, whether powered by gasoline or electricity.

Using today's electric grid, driving a fully electric pickup truck results in lower emissions than the most efficient hybrid pickup (37 mpg) for over 92 percent of the US population (Figure 3). In fact, the electric pickup produces lower emissions than the average new gasoline pickup (19 mpg) everywhere in the United States. On cleaner electric grids, even an inefficient electric pickup produces lower emissions than does a gasoline hybrid sedan. In California, recharging and driving the Rivian R1T or Ford F-150 Lightning pickup has the emissions impact of a hypothetical 76 mpg gasoline truck. Again, however, the goal is to lower emissions from personal transportation as quickly as possible; thus, buyers should choose the most efficient EV that meets their mobility needs.

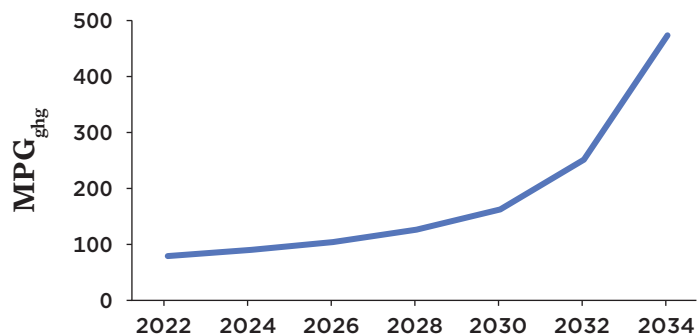
Driving an electric pickup truck in the United States produces emissions equal to a gasoline car getting 59 miles per gallon.

A Growing Advantage as Electricity Generation Becomes Cleaner

Most EVs charged using electricity generated in 2020 (the most recent available data) produce significantly lower emissions than even the most efficient gasoline vehicles. This advantage of EVs will continue to grow if emissions from electricity generation continue to fall. And if the United States aggressively decarbonizes such that renewables made up 95 percent of generation by 2035, emissions from driving EVs will drop to less than one-third of current levels by 2032 (Figure 4).

This is an important difference between EVs and gasoline vehicles. While the rate of global warming emissions from driving a gasoline vehicle will likely stay essentially constant, the emissions from driving an EV sold today will likely decline over time, effectively making it cleaner to use as the electricity grid gets cleaner.

FIGURE 4. Cleaner Electrical Generation Increases the Advantage of EVs



Nationally, the average EV's MPG_{ghg} rises from under 100 MPG_{ghg} today to the equivalent of a gasoline vehicle getting almost 500 miles to a gallon of fuel by 2035, assuming that the nation achieves 95 percent renewable power.

SOURCE: UCS CALCULATION BASED ON THE NREL CAMBIUM MODEL (COLE ET AL. 2021).

[CHAPTER 3

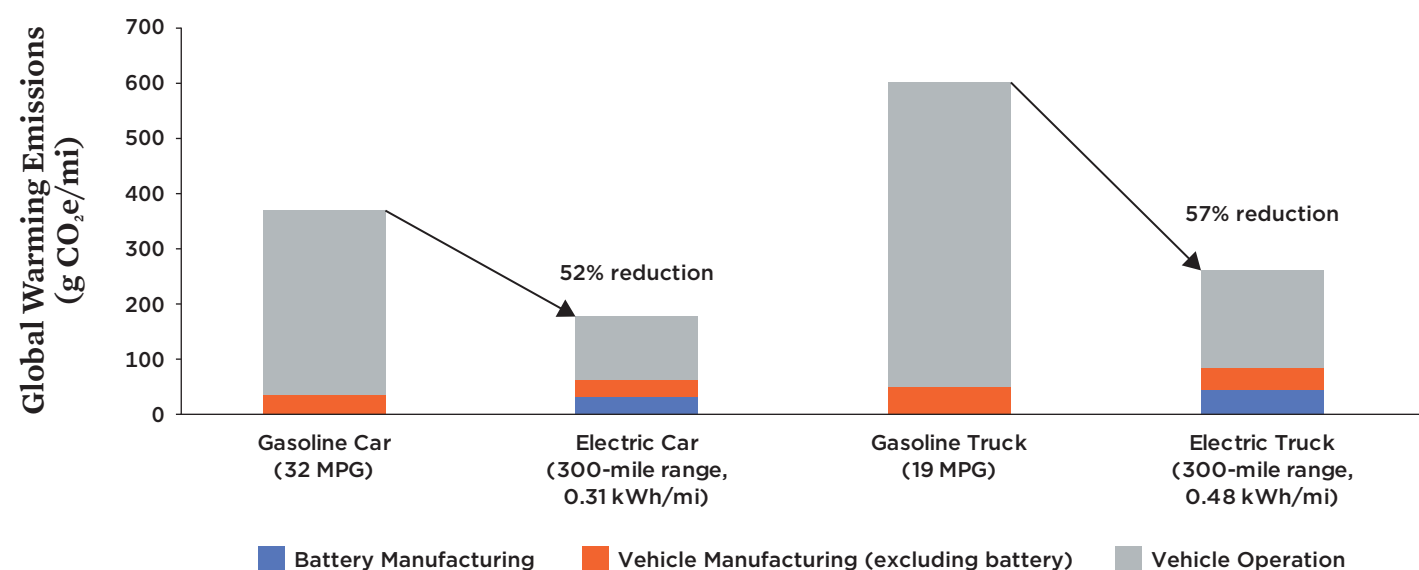
Global Warming Emissions from Vehicle Manufacturing

Just as the emissions associated with driving a battery-electric vehicle differ from those associated with driving a gasoline- or diesel-powered vehicle, so, too, do we find significant differences in the emissions due to their respective manufacturing processes. The greatest such differences come in connection with the type and size of batteries required. In gasoline vehicles, a small lead-acid battery starts the engine and powers accessories while the engine is off. In contrast, a battery-electric vehicle has no fuel tank or internal combustion engine; instead, it has a relatively large lithium-ion battery pack, an electric-drive motor, and power-control electronics. BEVs rely on the battery packs to move the vehicle and power all other systems (e.g., heating, air conditioning, electronics).

The lithium-ion battery packs in BEVs require significant amounts of material, with some packs weighing over 1,000 pounds. Extracting, processing, and transporting the raw materials all produce emissions. In addition, manufacturing the individual battery cells that comprise the battery packs requires significant energy, and that can lead to further global warming emissions.

That said, most of the life cycle global warming emissions for most of today's vehicles occur during their use. As a result, the emissions reductions from driving BEVs more than offset the increase in manufacturing emissions. Comparing the average gasoline sedan (32 mpg) with the average-efficiency BEV with a 300-mile-range battery, the BEV reduces total lifetime emissions by 52 percent (Figure 5). Even though manufacturing emissions

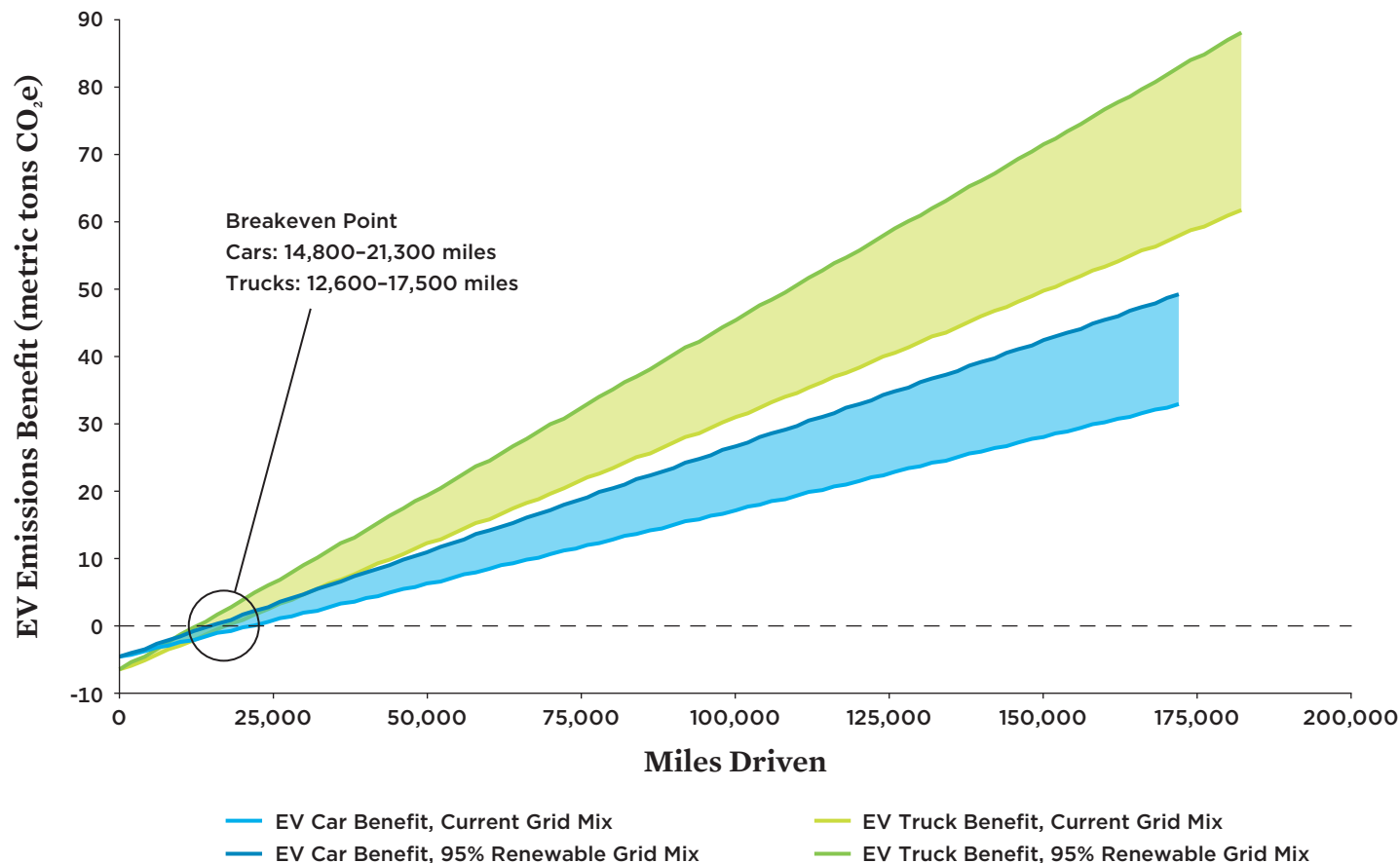
FIGURE 5. Life Cycle Global Warming Emissions: EVs vs. Gasoline Cars and Trucks



Life cycle global warming emissions are significantly lower for EVs than for gasoline cars or trucks when considering manufacturing and usage, despite higher battery-manufacturing emissions for the EV.

Note: Emissions are measured in grams of carbon dioxide-equivalent per mile, averaged over the life of the vehicle.

FIGURE 6. Breakeven Points for EV Car and Truck Emissions



The breakeven point for EV manufacturing emissions averages 17,500 miles (17 months) for 300-mile-range electric pickup trucks and 21,300 miles (22 months) for a 300-mile-range electric car, based on the current grid mix. This breakeven point assumes constant electricity emissions; actual breakeven points would be lower if electricity emissions fall over time.

average 64 grams per mile (g/mi) for the EV and 35 g/mi for a gasoline car, the savings advantage during use is far greater: the EV emits 117 g/mi versus 335 g/mi for the gasoline car. Similarly, lifetime emissions are 57 percent lower for an electric pickup truck than for the average gasoline pickup.

Another way to understand how emissions savings from driving an EV offset additional manufacturing emissions is to

consider the breakeven point: how far or how long an EV needs to drive for the savings to match the initial emissions “debt.” The breakeven point varies depending on regional electricity emissions. Based on where the US population lives, the mean breakeven point for an electric car with a 300-mile range compared with the average new gasoline sedan is 21,300 miles of driving or 22 months based on average annual driving (Figure 6). Breakeven occurs more quickly, after about 17,500 miles (17 months), when comparing an electric truck with a 300-mile range with the average new gasoline pickup truck.

For both cars and pickups, the breakeven point comes early in an EV’s lifetime, yielding a significant net emissions savings. If we were to consider EVs recharging using 95 percent renewable power, the breakeven points would drop to 14,800 miles for cars and 12,600 miles for trucks.

For both cars and pickups, the breakeven point comes early in an EV’s lifetime, yielding a significant net emissions savings.

TABLE 2. Switching to Renewable Electricity for Manufacturing: Another Opportunity to Reduce Life Cycle EV Emissions

	Battery	Vehicle (excluding battery)	Total	Percent Change vs. US Average
US Average Electric Mix	33.0 g/mi	28.5 g/mi	61.5 g/mi	0%
California (CAMX) Mix	29.5 g/mi	25.7 g/mi	55.2 g/mi	-10%
Upper Midwest (MRO) Mix	37.1 g/mi	31.7 g/mi	68.8 g/mi	+12%
Michigan–Ohio (RFC) Mix	33.0 g/mi	28.4 g/mi	61.4 g/mi	0%
100% Renewable Electricity	23.9 g/mi	21.1 g/mi	45.1 g/mi	-27%

Electric Grid Emissions and Manufacturing Emissions

The carbon intensity of electricity generation affects not only global warming emissions from driving but also those generated during the manufacture of the battery materials and the vehicle. Our baseline calculations for EV manufacturing use the average US electricity mix. However, we estimate that making an EV using electricity from the cleaner-than-average California regional grid would reduce total manufacturing emissions by 10 percent. And if the electricity for manufacturing comes solely from zero-carbon renewable energy sources, there is the potential to reduce manufacturing emissions by more than one-quarter (Table 2).⁴

TABLE 3. Emissions from Different Battery Chemistries, Relative to Those of NMC₁₁₁

NMC ₁₁₁	100%
NMC ₅₃₂	100%
NMC ₆₂₂	95%
NMC ₈₁₁	93%
NCA	109%
LFP	85%

The effects of different EV battery compositions on global warming emissions are relatively modest.

Notes: The number code associated with each NMC battery type refers to the proportion of nickel, manganese, and cobalt in the battery cathode. For example, NMC₁₁₁ refers to a lithium-nickel-manganese-cobalt cathode with 1:1:1 ratio of nickel:manganese:cobalt while NMC₅₃₂ has a ratio of 5:3:2 of nickel:manganese:cobalt. NCA is lithium-nickel-cobalt-aluminum; LFP is lithium iron phosphate.

Battery Chemistry: A Modest Effect on Global Warming Emissions

The raw materials for EV batteries vary depending on what cathode chemistry manufacturers choose as they strive to maximize performance, cost, and longevity. Most EV batteries today contain a lithium-nickel-manganese-cobalt (NMC), lithium-nickel-cobalt-aluminum (NCA), or lithium-iron phosphate (LFP) cathode.⁵ While the choice of chemistry can lead to significantly different environmental impacts, the effects of different EV battery compositions on global warming emissions are relatively modest (Table 3). Even so, the choice of battery chemistry is important: factors like the amount of cobalt in the mix could affect the cost, environmental, and societal impacts of mining; supply constraints could differ as well (Ambrose and O’Dea 2021; Winjobi, Kelly, and Dai 2022).

[CHAPTER 4

Other Battery Considerations

Considerations Beyond Global Warming Emissions

Manufacturing and using any vehicle, whether powered by gasoline or electricity, have impacts beyond the global warming emissions (Tessum, Hill, and Marshall 2014; EEA 2018). For example, air and water pollution from fossil fuel extraction are tied to the production of gasoline, as is electricity from fossil sources that partially power EVs in the United States. Also, there are concerns over human rights, corruption, and environmental pollution from the sourcing of raw materials that are used for EV manufacturing, as well as in the extraction of the crude oil that ultimately powers gasoline vehicles.

We focus here on the benefits of EVs in terms of global warming emissions, but some actions, like recycling battery materials, also can reduce the amount of virgin materials needed for battery manufacture. Such actions could reduce environmental damage and lessen harm to the people and communities affected by raw materials extraction and refining. Strong protections for communities and the environment at the mining stage are also critical to lessening the impacts of EV battery manufacturing. As the transition to electric transportation accelerates, government and industry need to ensure a battery supply chain that is sustainable and ethical.

Remanufacture, Reuse, and Second Life for Used EV Batteries

EV battery packs are made up of hundreds or thousands of individual battery cells, along with sophisticated electrical and thermal management systems. It is possible to disassemble used EV battery packs to repair, refurbish, or salvage usable modules. Doing so could help reduce global warming emissions and other harms: recovered components and refurbished battery packs lessen the need to manufacture new ones.

Another route to reducing the demand for new EV batteries is to repurpose used EV battery packs; such approaches are often termed second-life applications. The range of an EV battery

pack decreases both over time and with use. Because of tight constraints on the volume of an EV battery, this range reduction can make it necessary to replace the battery at some point in the vehicle's life, especially an EV with a lower initial range. However, other battery applications are less sensitive to the volume and weight of battery packs. For example, a stationary energy storage system might be able to use multiple EV battery packs with degraded capacity; the extra weight and volume of the battery packs are much less important in these applications than for an EV. A stationary battery installation with a few battery packs might power a building or an EV charging station; a megawatt-hour-scale energy storage system built with second-life batteries helps power the largest stadium in the Netherlands (Ambrose and O'Dea 2021; The Mobility House 2018).

Recycling Reduces Demand for Virgin Materials

After a battery is retired from use in an EV and reused and/or remanufactured, recycling can recover many of the materials that make up the battery pack. Recovered materials can reduce the need for virgin sourcing and reduce the emissions associated with refining and processing. Recycling can include pyrometallurgical and hydrometallurgical recycling processes, which reduces battery materials to elemental constituents, or direct cathode recycling, which recovers the full cathode. Pyrometallurgical recycling uses high-temperature smelting to recover “black mass,” a mixture of the metals found in batteries; hydrometallurgical recycling uses a leaching process to separate metals (Zheng et al. 2018). Hydrometallurgical and direct recycling yield small global warming emissions benefits in the EV life cycle, varying by the type of battery recycled (Ciez and Whitacre 2019). For a cathode of NMC chemistries, a model developed by the Argonne National Laboratory estimates that use of recycled materials can reduce total battery manufacturing emissions by about 20 percent (ANL 2021).⁶

Widespread recycling is critical regardless of the potential global warming benefits. As the market for EVs grows, battery recycling has the potential to significantly reduce the need for virgin materials and associated impacts of mining battery materials. These impacts include air and water pollution, water consumption, public health impacts, community disruption, and human rights concerns. Extractive industries have earned a reputation for frequently violating human rights and degrading the environment. For example, cobalt mining in the Democratic Republic of Congo, a country with 70 percent of the world's existing cobalt production and more than 50 percent of cobalt reserves, has well-documented negative impacts on the environment, community health, and human rights (NMIS, n.d; Amnesty International 2016).

Recycling battery materials can also help address concerns over the availability of critical materials such as cobalt, lithium, copper, nickel, and manganese. Under ideal conditions, between 20 and 60 percent of critical materials used in EV batteries could be derived from retired batteries by 2040 (Dunn et al. 2021; Xu et al. 2020). Various approaches are under development to capture the environmental, social, and energy-security benefits of increasing material circularity in the battery supply chain. In 2020, under California Assembly Bill 2832, the state tasked an advisory group with recommending policies that would lead as closely as possible to 100 percent recycling of EV batteries. The group's final report, released to legislators in March 2022, focuses on assigning a responsible party for EV recycling, enabling

access to battery information, supporting the repurposing and recycling industry, and increasing the safety and efficiency of reverse logistics (Kendall, Slattery, and Dunn 2022). In one notable recommendation, the vast majority of the group's members support extended producer responsibility, a policy that would assign EV manufacturers with the responsibility of ensuring the batteries are recycled when their lives end.

Both China and Japan have developed regulations regarding recycling used EV batteries. For example, China makes manufacturers responsible for battery recycling and specifies battery labeling to facilitate recycling. Japan makes new vehicle manufacturers responsible for battery disposal or recycling (Bird et al. 2022).

The European Union, which is also further along than the United States in developing end-of-life policy for EV batteries, has required extended producer responsibility for all battery types since the 2006 Battery Directive. The policy is not specific to EV batteries, but an updated version is in development to address social, environmental, and technical challenges throughout the EV supply chain and life cycle. A 2021 European Commission report proposes a policy focused on creating responsible, transparent, and lower-impact supply chains, with an emphasis on creating a circular economy. Proposed policies cover such topics as manufacturing and recycling emission standards, battery collection rates, recycling material recovery rates, manufacturing recycled content standards, and labeling requirements (European Commission 2020).

[CHAPTER 5

Policy Recommendations: Maximizing Emissions Reductions

Replacing gasoline vehicles with electric vehicles reduces carbon emissions and air pollution. To maximize those and other benefits, we must accelerate not only the adoption of EVs but also the transition to renewable sources of electricity. Moving forward with this dual transition constitutes a critical strategy for putting the United States on a trajectory toward net-zero climate emissions by midcentury.

Toward those goals, UCS makes the following recommendations.

- **Accelerate the transition to cleaner sources of electricity.** Reducing emissions from electricity generation can reduce the emissions from manufacturing and driving EVs. Policymakers at all levels should adopt and strengthen policies and programs for increasing energy efficiency and deploying renewable energy. Policy options include establishing renewable electricity standards, energy-efficiency resource standards, and incentives or mandates to improve grid operation, transmission, and resource planning. Future EVs with “smart charging,” which can respond to time-of-day and demand-related signals from electric utilities, can also play a role in enabling greater deployment of variable renewable energy from solar and wind.
- **Fund R&D aimed at lowering manufacturing emissions and increasing battery recycling and reuse.** Governments and the private sector should invest more in research aimed at decreasing the global warming emissions and other negative effects associated with making EV batteries, including research into the use of alternative materials and improving the processes for battery recycling and second-life use. “Recycling and second-life use” is an emerging sector of the economy; supporting it can encourage manufacturers to reduce emissions, and it also can reduce the need to extract raw materials. It is important to note research in these areas is ongoing, with funding at the federal and state levels. The 2021 Infrastructure Investment and Jobs Act (IIJA) includes funds for research, development, and demonstration to further battery recycling and second-life use (DOE 2022b; CRS 2022).
- **Enact policies that drive material circularity.** In addition to funding the development of improved battery recycling processes, public policies should ensure that batteries are recycled when they reach the end of their lives and that battery manufacturers use recovered materials. Increasing the recovery of critical materials has the potential to offset the use of virgin materials and reduce the environmental and social impacts associated with mining. Provisions in the IIJA support battery circularity, but more can be done. Policies like extended producer responsibility and labeling and collection requirements can help accelerate a circular economy.
- **Increase supply chain transparency, accountability, and sustainability.** EV manufacturers must be responsible for ethical and sustainable material sourcing throughout the supply chain and, to enable enforcement of this, they must

Public policies should ensure that batteries are recycled when they reach the end of their lives and that battery manufacturers use recovered materials.

ensure that their emissions and material sourcing are transparent to the public and regulators. Voluntary industry standards—the Initiative for Responsible Mining Assurance, for example—are a positive step, but only some manufacturers currently participate.⁷ Standardized, verifiable reporting of material and manufacturing processes, such as the Global Battery Alliance’s Battery Passport program, could help governments and nongovernmental organizations monitor and verify that battery production is environmentally sustainable and sourced using ethical practices (GBA 2020).

- **Minimize materials demand by increasing vehicle efficiency.** Vehicle efficiency standards should be developed to ensure that manufacturers produce high-efficiency EVs. Policies also should encourage vehicle buyers to purchase the most efficient EVs that meet their mobility needs. Higher-

efficiency EVs reduce per-mile emissions. Also, they make it possible for lower-capacity batteries to provide the needed range, reducing manufacturing emissions.

- **Decrease the need for individual car ownership.** Policies and funding should support a variety of transportation options—including transit, shared mobility options, and walking and biking infrastructure. This would further reduce materials demand and limit the overall emissions from vehicle manufacturing and use.
- **Promote equity in the transition to EVs.** Vehicle incentives and infrastructure deployment should enable drivers across incomes and geographies to access EVs. For us to reap the maximum benefits of EVs, all drivers must be able to switch from gasoline and diesel vehicles.

APPENDIX A: METHODOLOGY

Emissions Estimates for the Use Phase

The global warming emissions this study attributes to the use phase of operating an electric vehicle today result from producing the electricity needed to charge the vehicle. We factor in emissions created by power plants when generating the electricity, as well as emissions that result from obtaining and transporting the fuel used in these plants.

Power Plant Emissions

For the emissions values related to electricity generation, this analysis uses the Emissions & Generation Resource Integrated Database (eGRID) of the US Environmental Protection Agency (EPA). This is a comprehensive source of emissions data for every power plant in the United States. We used eGRID2020, the most up-to-date eGRID version available. It contains plant emissions and generation estimates for calendar year 2020 for the nation and for subregions, and it includes the mix of generation sources for each region. (EPA 2022a).

The subregions are groups of power plants organized by the EPA based on Power Control Areas and North American Reliability regions (EPA 2022b). These groupings, reflecting which plants serve which households, reasonably approximate the grid mix of electricity used by those households. The global warming emissions rates for electricity generation for each of the 26 regions analyzed in the report come from the eGRID2020 Subregion datasheet (EPA 2022a).

The level of disaggregation of the eGRID subregions, which takes into account regional variations in grid mix, allows for more precise calculations of plants' emissions intensities than does a national average. For this reason, we chose eGRID over other data sources that had the same detail in plant information but fewer subregions. The actual grid mix of a household's electricity is specific to the utilities serving each household, but specific grid-mix data are not readily available for most utilities and therefore are not used in the study.

The eGRID methodology treats subregions as closed systems, calculating the emissions intensity of generation for each subregion based on the emissions intensities of the plants it contains. This methodology ignores imports and exports of electricity between subregions, lessening the accuracy of regional emissions estimates. The eGRID's designers recommend the 26 subregions as the level of disaggregation best suited for estimating emissions related to electricity use; this achieves the best

balance between the precision gained by disaggregation and the accuracy lost by omitting imports and exports (EPA 2022b).

Transmission Loss Factors

The eGRID emissions rates do not account for transmission and distribution losses between power plants and households. To calculate emissions per unit of energy used (rather than energy produced), we increased the emissions rates using grid-loss factors found in data files (EPA 2022a).

There are five grid-loss factors that vary by regions called interconnect power grids; each state has a grid-loss factor based on the interconnect power grid to which it belongs. Although eGRID subregions are based on utility service territories that do not coincide with state boundaries, we assigned each subregion one of these factors based on those of the states. This avoids having multiple emissions rates for a single subregion serving two or more states with different grid-loss factors. For subregions that encompass parts of multiple states with different grid-loss factors, we used the most prevalent factor, based on the state with the largest geographic area in the subregion.

Upstream Emissions Factors

The eGRID subregion emissions rates include only emissions produced at the plant generating the electricity; the rates exclude upstream emissions resulting from the mining and transport of the power plant feedstock. Therefore, we calculated a feedstock emissions rate for each subregion; this rate depends on which fuel types the corresponding power plants use. Each fuel type has a unique upstream emissions rate, which we obtained from GREET—the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model. This is a publicly available life cycle emissions model developed by Argonne National Laboratory (ANL 2021). Our analysis used the AR5 Global Warming Potential values with 100-year time horizon. The percentage of generation from each fuel type in a subregion came from the eGRID2020 Subregion datasheet. For each subregion, we multiplied fuel-type emissions rates by the share of generation each represents in that subregion; the sum of these products was a subregion's feedstock emissions rate.

In GREET, most fuel types correspond directly to a fuel type in eGRID, with a few exceptions. A very small share of generation in eGRID subregions corresponds to a fuel type labeled “generic fossil.” For this fuel type, we chose the GREET

emissions rate for natural gas as a conservative guess, given that its upstream emissions value is higher than those of coal or oil (the other two fossil fuels with known feedstock emissions rates in GREET). An even smaller share of generation in eGRID subregions comes from unknown sources; for this category of fuel type, the feedstock emissions rate is the generation-weighted average of the upstream emissions rates for the other fuel types.

GREET builds a uniform grid-loss factor into the feedstock emissions rates. However, to keep the loss factors consistent with those applied to power plant emissions, we backed GREET's grid-loss factor out of the feedstock emissions rates. We then applied eGRID's power plant grid-loss factors to each subregion's feedstock emissions rate.

We computed the totals of global warming emissions related to electricity generation for each eGRID subregion by summing the grid-loss-adjusted power plant emissions rates for each subregion with the corresponding grid-loss-adjusted feedstock emissions rate.

Emissions Rate Assumptions and Results by Subregion

To translate electricity-related emissions intensity into driving-related emissions intensity (measured as a gasoline miles-per-gallon equivalent, or MPG_{ghg}), we multiplied the EPA emissions intensity values (expressed in grams of carbon dioxide-equivalent emissions per kilowatt-hour, or $\text{gCO}_2\text{e/kWh}$) from Table A-1 (see p. 21) by the EV average efficiency values (kWh/mile), resulting in a $\text{gCO}_2\text{e/mile}$ estimate. EV average efficiency was calculated using the sales-weighted average electric-drive efficiency (including charging losses) of the 10 battery EVs and 10 plug-in hybrid EVs (PHEVs) with the highest US sales over the past six years (DOE 2022a; EV Hub 2022). PHEV efficiencies were weighted by utility factor. The overall average efficiency for all EVs was 0.314 kWh/mi .

We used the GREET carbon intensity for a weighted average of California and national gasoline on a lower heating value basis ($10.629 \text{ kg CO}_2\text{e/gal}$), which includes emissions for petroleum extraction, gasoline refining and production, transportation of finished product, and combustion (ANL 2021). This intensity was divided by the $\text{gCO}_2\text{e/mile}$ estimate to estimate the MPG_{ghg} for each region. This figure is an EV equivalent to the miles per gallon of a gasoline-powered vehicle: vehicles with the same MPG_{ghg} will produce the same amount of global warming pollution for each mile traveled, regardless of the type of fuel.

Emissions Estimates for the Manufacturing Phase

To model vehicle manufacturing, we used the 2021 versions both of GREET 1 (a fuel-cycle model) and GREET 2 (a vehicle-cycle

model). In the absence of specific details about the material composition of the gasoline and battery-electric models, we used model default values for cars and trucks. The EV car was modeled as having a 300-mile range with a 95 kWh battery capacity. EV pickups were modeled using a 300-mile-range battery of 135 kWh capacity. We used the GREET default vehicle lifetime: 173,151 miles for cars and 183,363 miles for pickup trucks.

Temperature Effects on Efficiency and Emissions

Temperature affects the efficiency of both gasoline and electric vehicles, with reduced efficiency—and hence increased emissions—at both hot and cold temperatures. Effects generally appear at temperatures above 75°F and below 60°F (Wu et al. 2019). However, we did not adjust the data for temperature effects because of uncertainty in the magnitude of that effect, especially for newer EVs.

For EVs, the most significant decrease in efficiency occurs at low temperatures. This decrease stems from several sources. First, while a gasoline vehicle can use waste heat from the engine to warm the cabin, an EV must use energy from the battery to power heating systems. Second, warming the battery in many EVs improves battery longevity and performance. On the other hand, lower temperatures reduce the performance of lithium-ion batteries, with higher internal resistance. In addition, the ability of EVs to recoup energy during braking can be limited at lower temperatures (Steinstraeter, Heinrich, and Lienkamp 2021).

However, quantification of such efficiency changes is hampered by the lack of data on the performance of new models of gasoline and electric vehicles at high and low ambient temperatures. Further complicating the analysis is the emerging use of heat pump systems in newer EV models. Heat pumps can be more efficient than the resistance heating systems commonly found in the first generation of modern EVs and can lead to a smaller reduction in EV efficiency in cold weather (Phillips 2022). Existing quantitative analyses of EV cold-weather performance, such as by Wu et al. (2019), necessarily rely on data from early EV models; they may not reflect the performance of EVs now available for purchase in the United States.

Because of the uncertainty in the magnitude of the temperature effect on efficiency, especially for newer EVs, the data presented in the body of this report are not adjusted for temperature effects. Based on the methods and data from Woody et al. (2022), we estimate the US average MPG_{ghg} value for an average efficiency EV would be $77 \text{ MPG}_{\text{ghg}}$. However, this may underestimate the emissions benefits from newer EVs with heat pumps or other cold-weather optimizations.

TABLE A-1. eGRID Subregion Electricity Emissions Rates and EV Use-Phase Emissions

eGRID Subregion Acronym	eGRID Subregion Name	2020 Subregion Average Emissions Rate (gCO ₂ e/kWh)	Use Phase Emissions, Average EV (gCO ₂ e/mi)	Use Phase Emissions, Most Efficient EV (gCO ₂ e/mi)
AKGD	ASCC Alaska Grid	605	190	145
AKMS	ASCC Miscellaneous	303	95	73
ERCT	ERCOT All	447	141	107
FRCC	FRCC All	472	148	113
HIMS	HICC Miscellaneous	652	205	156
HIOA	HICC Oahu	914	287	219
MROE	MRO East	799	251	192
MROW	MRO West	507	159	122
NYLI	NPCC Long Island	661	208	159
NEWE	NPCC New England	305	96	73
NYCW	NPCC NYC/Westchester	366	115	88
NYUP	NPCC Upstate NY	137	43	33
RFCE	RFC East	365	115	88
RFCM	RFC Michigan	615	193	148
RFCW	RFC West	523	164	125
SRMW	SERC Midwest	767	241	184
SRMV	SERC Mississippi Valley	418	131	100
SRSO	SERC South	473	149	114
SRTV	SERC Tennessee Valley	445	140	107
SRVC	SERC Virginia/Carolina	344	108	83
SPNO	SPP North	495	156	119
SPSO	SPP South	502	158	120
CAMX	WECC California	291	91	70
NWPP	WECC Northwest	318	100	76
RMPA	WECC Rockies	598	188	144
AZNM	WECC Southwest	461	145	111

The average EV has an efficiency of 0.314 kWh/mi; the most efficient EV has an efficiency of 0.24 kWh/mi.

APPENDIX B: AVERAGE AND MARGINAL ELECTRICITY EMISSIONS CONSIDERATIONS

Electricity is produced using a mix of generation units that vary in size, fuel, and efficiency. The mix varies over both long and short time scales: the demand for electricity, its availability, and the fuel costs are always changing. Emissions attributable to electricity use link directly to this generation mix, and they vary by region, time of year, and time of day. Because of the complexity of the electricity grid and how it operates, as well as the inability to track specific electricity generation to a specific end use, multiple methods have been developed to estimate the emissions from electricity use. This analysis used an average emissions approach, averaging the emissions from electricity production over all the electricity generating units in an entire electricity grid region for a year.

Average Emissions Estimation

We based the data used to calculate regional global warming emissions intensities on actual power plant emissions for 2020.

To estimate EV emissions from plugging into the electricity grid, we calculated the average intensity of global warming emissions (i.e., emissions emitted for each net kilowatt-hour of electricity delivered) by region. This method of averaging emissions intensity treats all electricity produced and consumed in the region equally. That is, no matter how much electricity you use or when you use it, this method assumes your electricity to be just as clean (or dirty) as anyone else's in the same region. In essence, it assumes that any additional electricity needed to power an EV would come from the same mix of sources that generate electricity to meet all other current demands.

The averaging approach makes it possible to capture changes in the underlying generation mix when estimating future years' emissions. However, it does not reflect short-term changes in the electricity grid that may result from adding a new electricity load to the grid. Nor does the average emissions approach account for the import and export of electricity across regions.

Marginal Emissions Estimation

An alternative approach involves "marginal" emissions intensity. This is estimated by identifying which power plants, or types of power plant, are likely to be deployed or to increase output when new demand is added to the electricity grid above and beyond existing demand. In this type of analysis, the electricity consumed by an additional load, such as a newly purchased EV or even an extra television set, would be assigned a different

emissions intensity from electricity used by existing electric loads (e.g., a light fixture in a home). A variety of analyses have used various marginal emissions approaches to evaluate the potential impacts of increasing amounts of EV charging on future emissions of the electricity grid (EPRI and NRDC 2015; Tamayao et al. 2015; Graff Zivin, Kotchen, and Mansur 2014). These marginal emissions analyses can be broken into two categories: short term and long term.

Short-Term Marginal Emissions Analysis

The short-term method looks at how the electricity grid responds instantaneously to a new load, such as when an EV is plugged in. This approach specifically ties the emissions from plugging in the EV to how the grid would respond to the new load, all other factors being fixed. Increases in electricity demand are met through increasing generation output at a power plant operating at less than full output—typically, a natural gas or coal power plant. These types are considered the marginal generation sources. In contrast, sources such as nuclear, hydro, wind, and solar are rarely "on the margin" because of their limited ability to vary output. These electricity sources provide non-marginal generation.

This short-term marginal emissions approach can provide a more precise snapshot of how the grid responds to a new load during a short amount of time, and it quantifies the net emissions change during that period. Carrying out the same type of analysis in future years could produce very similar results, regardless of changes to nonmarginal load generation. For example, if over some time period 25 percent of electricity generation in a region moved to renewable sources, fossil fuel power plants might still be the only electricity sources on the margin responding to instantaneous increases in demand for electricity. Using this type of marginal emissions analysis, an EV powered on a grid with no renewables and one with 25 percent renewables might have the same emissions profile.

Eventually, new electricity demand will lead to changes in the sources of electricity production. Over time, a large number of EVs will create significant demand that must be met through greater energy efficiency, increased utilization of existing sources, new electricity generation, or, very likely, a combination of all three.

Long-Term Marginal Emissions Analysis

A short-term marginal analysis considers only increased utilization of existing generating resources, although researchers have looked into a more consequential approach with new capacity as a consideration (Weis, Jaramillo, and Michalek 2014). The long-term marginal emissions approach, also known as a consequential life cycle approach, evaluates how the electricity grid responds over a longer period. This approach estimates what would happen to the grid without adding new electricity load, then contrasts that outcome with what would happen under the new load. For example, an analysis could estimate electricity demand between 2015 and 2030 assuming no EVs, then estimate demand with several million EVs added (EPRI and NRDC 2015).

This type of modeling approach makes it possible to evaluate long-term changes in the electricity grid, including power plant retirements, new electricity generation, and changes in EV demand. Importantly, it also makes it possible to evaluate policies to reduce emissions from both the transportation and electricity sectors, as well as to estimate the cumulative impact on emissions from both sectors.

While a long-term marginal emissions approach does not tell us what the emissions are from EVs today, it is an important tool for assessing the impacts of transportation and energy policies designed to reduce emissions—of deploying more EVs while also deploying cleaner electricity sources. However, this

approach is outside the scope of our analysis because it requires modeling the transportation and energy sectors as well as the specific changes to the electricity grid that might occur under various future scenarios.

Why We Used Average Emissions Estimation

The goal of this analysis was to identify the typical global warming emissions of the mix of electricity sources used to charge EVs on today's power grid, as well as to evaluate how that mix changes over time and compares with past and possible future electricity grids. Therefore, we used the average emissions intensity of the electricity, essentially treating all electricity on the grid at a given time as a shared resource available to all electricity consumers. While this approach does not capture the very short-term marginal emissions impact on the grid from plugging in a new EV, it does reflect changes occurring in nonmarginal load generation around the country.

The average emissions approach also allows for comparing future and past emissions analyses, and it captures the impact of ongoing changes to the electricity grid as a whole resulting from regulatory policy and other factors. In other words, as consumers buy EVs today, the approach can take into account the trajectory of the grid and the global warming emissions over the life of the vehicles.

ENDNOTES

1. This report investigates the global warming potential for emissions from gasoline- and electricity-powered vehicles. Global warming leads to climate change (a broader set of impacts), so we refer to the emissions as both “global warming” and “climate changing.”
2. Average EV efficiency is based on a sales-weighted average of EPA combined highway and city efficiency values for the 10 battery-electric and 10 plug-in hybrid electric models with the highest US sales over the last six years. Plug-in hybrid EV efficiencies are also weighted by utility factor.
3. Based on EV sales from 2016 through 2021.
4. This analysis does not model the potential emissions reductions from decarbonization of material production.
5. The cathode is the positive electrode of the battery. For the battery to charge and discharge, lithium ions pass between the cathode and anode (negative electrode). Between the electrodes are electrolyte and a separator used to prevent a short circuit.
6. The model is GREET—the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model. GREET is a publicly available life cycle emissions model.
7. For information on the Initiative for Responsible Mining Assurance, see <https://responsiblemining.net>.

REFERENCES

- Ambrose, Hanjiro, and Jimmy O'Dea. 2021. *Electric Vehicle Batteries: Addressing Questions about Critical Materials and Recycling*. Cambridge, MA: Union of Concerned Scientists. <https://www.ucsusa.org/resources/ev-battery-recycling>
- Amnesty International. 2016. *"This Is What We Die For": Human Rights Abuses in the Democratic Republic of the Congo Power the Global Trade in Cobalt*. London, England. <https://www.amnesty.org/en/documents/afr62/3183/2016/en>
- Anair, Don, and Amine Mahmassani. 2012. *State of Charge: Electric Vehicles' Global Warming Emissions and Fuel-Cost Savings across the United States*. Cambridge, MA: Union of Concerned Scientists. <https://www.ucsusa.org/resources/state-charge>
- ANL (Argonne National Laboratory). 2021. "The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model," released October 11. <https://greet.es.anl.gov/index.php>
- Baek, Y., T. Boettner, R. Cleetus, S. Clemmer, C. Esquivia-Zapata, C. Farley, B. Isaac, et al. 2021. *A Transformative Climate Action Framework: Putting People at the Center of Our Nation's Clean Energy Transition*. Cambridge, MA: Union of Concerned Scientists. <https://www.ucsusa.org/clean-energy-transformation>
- Bird, Robert, Zachary J. Baum, Xiang Yu, and Jia Ma. 2022. "The Regulatory Environment for Lithium-Ion Battery Recycling." *ACS Energy Letters* 7 (2): 736–740. DOI: 10.1021/acsenerylett.1c02724
- CARB (California Air Resources Board). 2022. *Public Hearing to Consider the Proposed Advanced Clean Cars II Regulations. Staff Report: Initial Statement of Reasons*. Sacramento CA. <https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/isor.pdf>
- Ciez, Rebecca E., and J. F. Whitacre. 2019. "Examining Different Recycling Processes for Lithium-Ion Batteries." *Nature Sustainability* 2: 148–56. <https://doi.org/10.1038/s41893-019-0222-5>
- Cole, Wesley, J. Vincent Carag, Maxwell Brown, Patrick Brown, Stuart Cohen, Kelly Eurek, Will Frazier, et al. 2021. *2021 Standard Scenarios Report: A U.S. Electricity Sector Outlook*. NREL/TP-6A40-80641. Golden, CO: National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy22osti/80641.pdf>
- CRS (Congressional Research Service). 2022. *Energy and Minerals Provisions in the Infrastructure Investment and Jobs Act (P.L. 117-58)*. Washington, DC. <https://crsreports.congress.gov/product/pdf/R/R47034>
- DOE (Department of Energy). 2022a. "FuelEconomy.gov: The Official U.S. Government Source for Fuel Economy Information." www.fueleconomy.gov
- . 2022b. "Biden Administration Announces \$3.16 Billion from Bipartisan Infrastructure Law to Boost Domestic Battery Manufacturing and Supply Chains." Press release, May 2. <https://www.energy.gov/articles/biden-administration-announces-316-billion-bipartisan-infrastructure-law-boost-domestic>
- Dunn, Jessica, Margaret Slattery, Alissa Kendall, Hanjiro Ambrose, and Shuhan Shen. 2021. "Circularity of Lithium-Ion Battery Materials in Electric Vehicles." *Environmental Science & Technology* 55 (8): 5189–5198. <https://pubs.acs.org/doi/10.1021/acs.est.0c07030>
- EEA (European Environment Agency). 2018. *Electric Vehicles from Life Cycle and Circular Economy Perspectives*. Copenhagen, Denmark. <https://www.eea.europa.eu/publications/electric-vehicles-from-life-cycle>
- EPA (Environmental Protection Agency). 2021a. "Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions 1990–2019." <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockkey=P1013NR3.pdf>
- . 2021b. *The 2021 EPA Automotive Trends Report: Greenhouse Gas Emissions, Fuel Economy, and Technology Since 1975*. Washington, DC. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockkey=P1013L10.pdf>
- . 2022a. "The Emissions & Generation Resource Integrated Database (eGRID) (eGRID2020)." <https://www.epa.gov/egrid/download-data>
- . 2022b. "The Emissions & Generation Resource Integrated Database eGRID Technical Guide with Year 2020 Data." <https://www.epa.gov/egrid/download-data>
- EPRI and NRDC (Electric Power Institute and Natural Resources Defense Council). 2015. *Environmental Assessment of Full Electric Transportation Portfolio*. Palo Alto, CA. <https://www.epri.com/research/products/3002006881>
- European Commission. 2020. *Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020PC0798>
- EV Hub. 2022. "New State Registrations." <https://www.atlasevhub.com/materials/evgridx/> (paywall restricted)
- GBA (Global Battery Alliance). 2020. *The Global Battery Alliance Battery Passport: Giving an Identity to the EV's Most Important Component*. Briefing Paper. <https://www.globalbattery.org/media/publications/wef-gba-battery-passport-overview-2021.pdf>
- Graff Zivin, Joshua S., Matthew J. Kotchen, and Erin T. Mansur. 2014. "Spatial and Temporal Heterogeneity of Marginal Emissions: Implications for Electric Cars and Other Electricity-Shifting Policies." *Journal of Economic Behavior & Organization* 107: 248–268. <https://www.sciencedirect.com/science/article/pii/S0167268114000808>
- Kendall, Alissa, Margaret Slattery, and Jessica Dunn. 2022. *Lithium-ion Car Battery Recycling Advisory Group Final Report*. Prepared on behalf of the AB 2832 Advisory Group for the California Environmental Protection Agency. Sacramento, CA. https://calepa.ca.gov/wp-content/uploads/sites/6/2022/05/2022_AB-2832_Lithium-Ion-Car-Battery-Recycling-Advisory-Goup-Final-Report.pdf

- The Mobility House. 2018. "The 3 Megawatt Energy Storage System in Johan Crujff ArenA Is Now Live." Press release, June 29. https://www.mobilityhouse.com/int_en/magazine/press-releases/johan-crujff-arena-3mw-energy-storage-system-launch.html
- NMIS (National Mineral Information Center). n.d. "Cobalt Statistics and Information." Accessed June 8, 2022. <https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information>
- Nealer, Rachael, David Reichmuth, and Don Anair. 2015. *Cleaner Cars from Cradle to Grave: How Electric Cars Beat Gasoline Cars on Lifetime Global Warming Emissions*. Cambridge, MA: Union of Concerned Scientists. <https://www.ucsusa.org/resources/cleaner-cars-cradle-grave>
- Phillips, Sam. 2022. "Revealed: How Winter Weather Affects Real-World Range." Move Electric.com, March 17. <https://www.moveelectric.com/e-cars/revealed-how-winter-weather-affects-real-world-range>
- Steinstraeter, Matthias, Tobias Heinrich, and Markus Lienkamp. 2021. "Effect of Low Temperature on Electric Vehicle Range." *World Electric Vehicle Journal* 12: 115. <https://doi.org/10.3390/wevj12030115>
- Tamayao, Mili-Ann, Jeremy J. Michalek, Chris Hendrickson, and Inês M. L. Azevedo. 2015. "Regional Variability and Uncertainty of Electric Vehicle Life Cycle CO₂ Emissions Across the United States." *Environmental Science & Technology* 49 (14): 8844–8855. <http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00815>
- Tessum, Christopher W., Jason D. Hill, and Julian D. Marshall. 2014. "Life Cycle Air Quality Impacts of Conventional and Alternative Light-Duty Transportation in the United States." *Proceedings of the National Academy of Sciences* 111 (52): 18490–18495. <https://doi.org/10.1073/pnas.1406853111>
- Weis, Allison, Paulina Jaramillo, and Jeremy Michalek. 2014. "Estimating the Potential of Controlled Plug-In Hybrid Electric Vehicle Charging to Reduce Operational and Capacity Expansion Costs for Electric Power Systems with High Wind Penetration." *Applied Energy* 115: 190–204. <https://www.sciencedirect.com/science/article/pii/S0306261913008374>
- Winjobi, Olumide, Jarod C. Kelly, and Qiang Dai. 2022. "Life-Cycle Analysis, by Global Region, of Automotive Lithium-Ion Nickel Manganese Cobalt Batteries of Varying Nickel Content." *Sustainable Materials and Technologies* 32: e00415. <https://www.sciencedirect.com/science/article/pii/S221499372200029X>
- Woody, Maxwell, Parth Vaishnav, Gregory A. Keoleian, Robert De Kleine, Hyung Chul Kim, James E. Anderson, and Timothy J. Wallington. 2022. "The Role of Pickup Truck Electrification in the Decarbonization of Light-Duty Vehicles." *Environmental Research Letters* 17 (3): 034031. <https://iopscience.iop.org/article/10.1088/1748-9326/ac5142>
- Wu, Di, Fendi Guo, Frank R. Field, Robert D. De Kleine, Hyung C. Kim, Timothy J. Wallington, and Randolph E. Kirchain. 2019. "Regional Heterogeneity in the Emissions Benefits of Electrified and Lightweighted Light-Duty Vehicles." *Environmental Science & Technology* 53 (18): 10560–70. <https://doi.org/10.1021/acs.est.9b00648>
- Xu, Chengjian, Qiang Dai, Linda Gaines, Mingming Hu, Arnold Tukker, and Bernhard Steubing. 2020. "Future Material Demand for Automotive Lithium-Based Batteries." *Communications Materials* 1: 99. <https://doi.org/10.1038/s43246-020-00095-x>
- Zheng, Xiaohong, Zewen Zhu, Xiao Lin, Yi Zhang, Yi He, Hongbin Cao, and Zhi Sun. 2018. "A Mini-Review on Metal Recycling from Spent Lithium Ion Batteries." *Engineering* 4 (3): 361–370. <https://doi.org/10.1016/j.eng.2018.05.018>

Driving Cleaner

Electric Cars and Pickups Beat Gasoline on Lifetime Global Warming Emissions

Passenger cars and trucks are one of the largest sources of global warming emissions in the United States. Electric vehicles (EVs) have the potential to dramatically reduce these emissions, especially when charged by low-carbon renewable electricity. New UCS analysis finds that over its lifetime—from manufacturing to operation to disposal—the average new battery electric vehicle produces more than 50 percent less global warming pollution than a comparable gasoline or diesel vehicle. Based on the most recently available data on power plant emissions and EV sales, driving the average EV in the United States produces global warming emissions equal to a gasoline vehicle that gets 91 miles per gallon. To speed climate benefits and to encourage more drivers to choose electric vehicles, the report recommends policy changes and investments to bring even more renewable energy onto the grid, develop robust battery recycling programs to help reduce manufacturing impacts, and make EVs more accessible and affordable.

**Union of
Concerned Scientists**

www.ucsusa.org/resources/driving-cleaner

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Today's Electric Vehicles Can Greatly Reduce Emissions From Driving

March 20, 2023 | 2:03 pm



David Reichmuth

Senior Engineer, Clean Transportation Program

Transportation is the largest source of global warming emissions in the US and the passenger vehicles many of us drive are responsible for the majority of transportation global warming emissions. Avoiding the worst impacts of climate change will require the rapid reduction in these emissions from the vehicles we drive. Electric vehicles (EVs) can eliminate tailpipe emissions altogether and are also more efficient than gasoline vehicles making EVs an important technology for reducing both global-warming and harmful air pollution from personal transportation.

In 2022, my colleagues and I analyzed the global warming emissions benefits of electric cars and trucks in our report “Driving Cleaner.” Earlier this year, the EPA released newer power plant emissions data, which I’ve used to update our assessment of the relative benefit of driving an EV as compared to the gasoline alternative.



As new, more affordable EV models like this Chevy Equinox become

available, more drivers will be able to reduce their emissions from driving. (UCS/Reichmuth)

Comparing EV and gasoline vehicle emissions

When we compare driving on electricity versus gasoline, we consider the global warming emissions that occur in producing and using those fuels. For a fully-electric EV, that means:

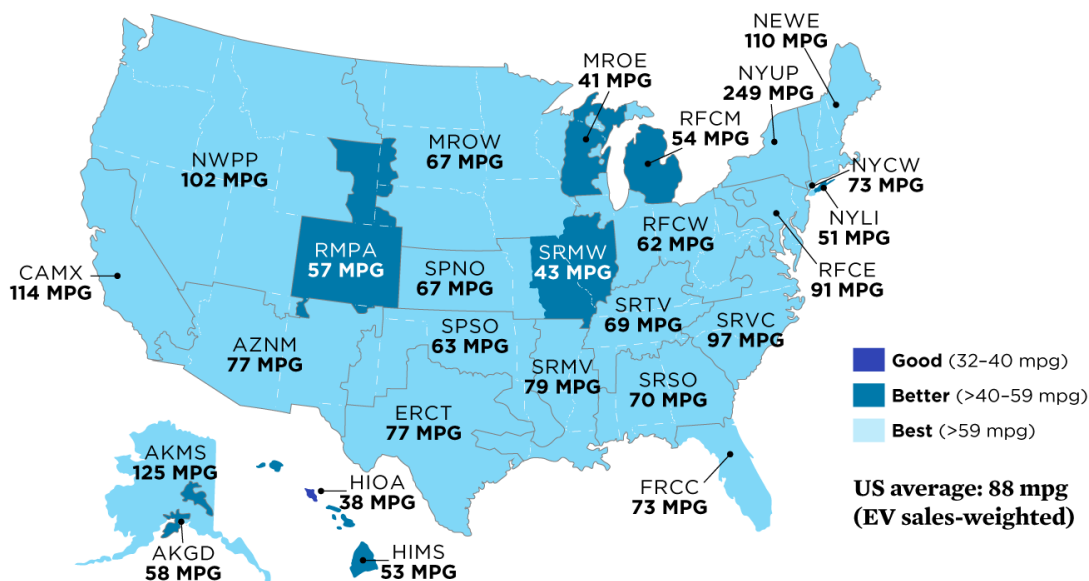
- Emissions that result from raw-material extraction, such as coal mining and natural gas drilling;
- Emissions from delivering these fuels to power plants;
- Emissions from burning those fuels in power plants to generate electricity;
- Electricity losses that occur during distribution from power plants to the point where the electric vehicle is plugged in; and
- The efficiency of the vehicle in using electricity.

Similarly, our assessment of the global warming emissions from comparable gasoline and diesel vehicles addresses emissions that result from:

- Oil extraction at the well;
- Transporting crude oil to a refinery;
- Refining oil into gasoline;
- Delivering fuel to gas stations; and
- Combusting fuel in the vehicle's engine.

Because of differences in electricity generation across the United States, the emissions produced from driving the average EV varies depending on where the vehicle is driven. Despite this variance, driving the *average* EV results in lower emissions than the *average* new gasoline vehicle everywhere in the United States.

Comparing Emissions: Driving the Average EV as a Gasoline MPG Equivalent, 2021



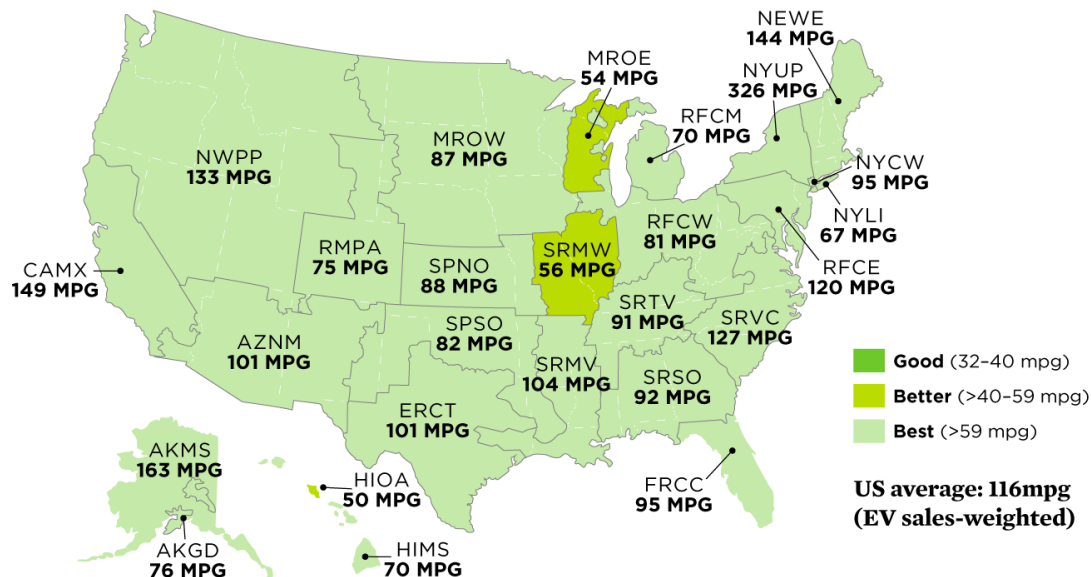
Over 90 percent of people in the United States live where driving the average EV produces fewer global warming emissions than the most efficient gasoline vehicle (57 mpg). Based on where EVs have been sold in the United States, driving on electricity produces emissions equal to those of a gasoline car getting 88 miles per gallon. Note: Acronyms refer to electricity grid regions as defined by [EPA's eGRID database](#).

Driving a more efficient EV maximizes the benefits

While using the average efficiency EV has clear climate benefits compared to gasoline-powered vehicles, emission reductions are maximized by choosing the most efficient EVs available. Vehicles like the Lucid Air and Tesla Model 3 require the least amount of electricity per mile because of their more efficient powertrains and low aerodynamic drag design. A high-efficiency design also means that a smaller capacity and therefore lighter battery pack can be used to achieve the desired driving range, further reducing the energy required to move the car. These most-efficient EVs have lower driving emissions than every gasoline model for 97% of people in the country. In many parts of the US, including the entire West Coast and New

England, driving one of these EVs means global warming emissions are [less than a quarter of the average gasoline vehicle](#).

Comparing Emissions: Driving the Most Efficient EV as a Gasoline MPG Equivalent, 2021



Choosing the most-efficient EV minimizes emissions from driving. For example, drivers of the most efficient EV in New England will produce global warming emission equal to a hypothetical 144 MPG gasoline-powered car.

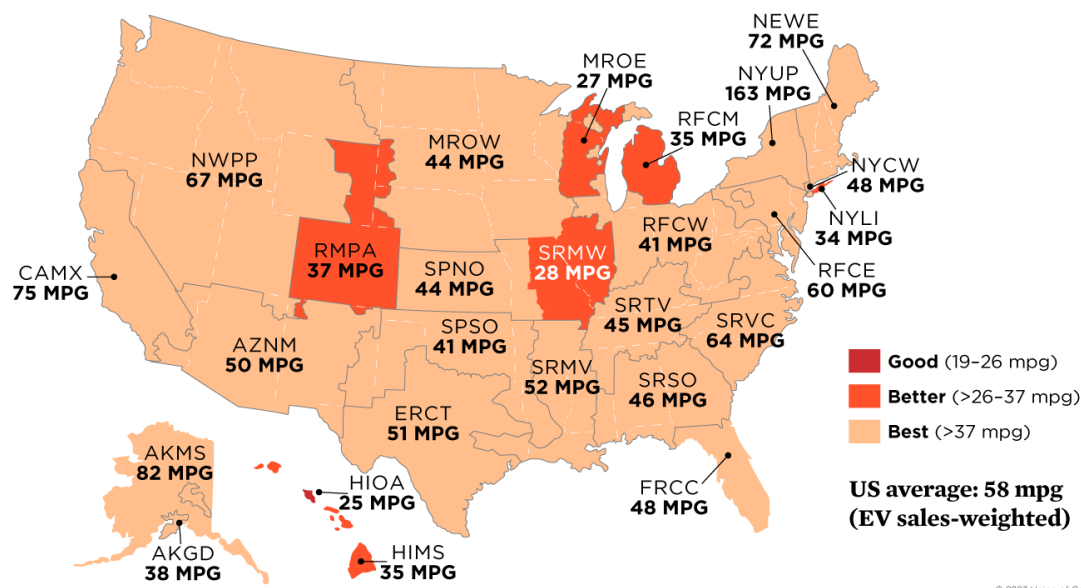
Electrifying larger vehicles like pickups can also reduce emissions

Larger EVs are now available, including [an electric version of the Ford F-150 pickup truck](#), the [best-selling vehicle in the US](#). Larger vehicles, whether gasoline or electric-powered, are less efficient than the average car. However, switching from gasoline to electricity still has an advantage. Everywhere in the United States, the emissions from driving an EV pickup truck are lower than those for the average new gasoline or diesel pickup truck.

Switching from a gasoline truck to an EV truck has clear benefits and is a good choice for drivers that need the hauling or towing ability of

these vehicles. However, moving from an efficient gasoline car to a large EV like a pickup truck can reduce the climate benefits of electrification. To reduce emissions, drivers should choose EVs over gasoline vehicles when possible. But regardless of the fuel, car buyers should choose more efficient models that meet their mobility needs, both to reduce emissions from driving and to save on fuel costs. Simply put, electrification shouldn't be seen as justification to [drive a Hummer](#).

Comparing Emissions: Driving the Average EV Pickup Truck as a Gasoline MPG Equivalent, 2021



Driving an electric pickup truck produces lower emissions than the most efficient gasoline model in most of the United States. For example, recharging and driving the Rivian R1T or Ford F-150 Lightning pickup in New England has the emissions impact of a hypothetical 72 mpg gasoline truck. Overall, based on where EVs have been sold, EV pickups on average would have emissions equal to a 58 mpg gasoline truck, significantly better than gasoline trucks.

Avoiding driving altogether is even better than driving an EV

Choosing to drive an EV (especially a more efficient one) instead of a gasoline car will help reduce carbon pollution that is a major cause of climate change. And this choice to drive using electricity is now significantly cleaner than when we [first looked at the benefits of EVs](#). However, avoiding driving is even better. Using mass transit instead of a personal vehicle can reduce emissions. And walking and biking means avoiding air pollution and climate-changing emissions altogether. With our current transportation system, it's difficult for many people to switch all of their trips to transit, walking, or biking, but using these modes even part of the time can make a positive difference in the pollution from personal transportation.

Posted in: [Transportation](#)

Tags: [electric vehicle](#), [global warming emissions](#), [Maps](#)

Are There Enough Materials to Manufacture All the Electric Vehicles Needed?

November 15, 2022 | 8:44 am



Jessica Dunn
Senior Analyst

The short answer is yes. But this is a complicated question, so let's dig in further.

The transition to electric vehicles (EVs) is necessary to [decrease](#) climate-changing emissions. As deployment increases, so will the demand for EV battery materials such as lithium, cobalt, and nickel. These materials are primarily supplied through two sources: 1) newly mined or 2) recovered by [recycling](#) batteries already in circulation.

Using recycled materials results in significantly less environmental impacts and is a substitute for those newly mined, although it requires the materials to have already been extracted, manufactured into a battery, and then retired from use.

[Research](#) shows there are enough explored or prospective reserves to electrify the global transportation sector using current technology *if* a high amount of battery recycling occurs. In this scenario, global demand in 2100 will amount to about 55% of cobalt reserves and 50% of lithium reserves.

This is in stark contrast to a future without high recycling rates.

If recycling doesn't ramp up, a shortage of [lithium](#), [nickel](#), or [cobalt](#) is not likely, but it is estimated that the demand would exceed what is economically accessible to extract. In this scenario, demand in 2060 is more than cobalt reserves and about 90% of lithium reserves. In other words, for the forecasted demand to be met, extraction must go beyond what is seen as economically viable. This dwindling of reserves would likely raise material costs, triggering increased exploration and development, and potentially expand reserves.

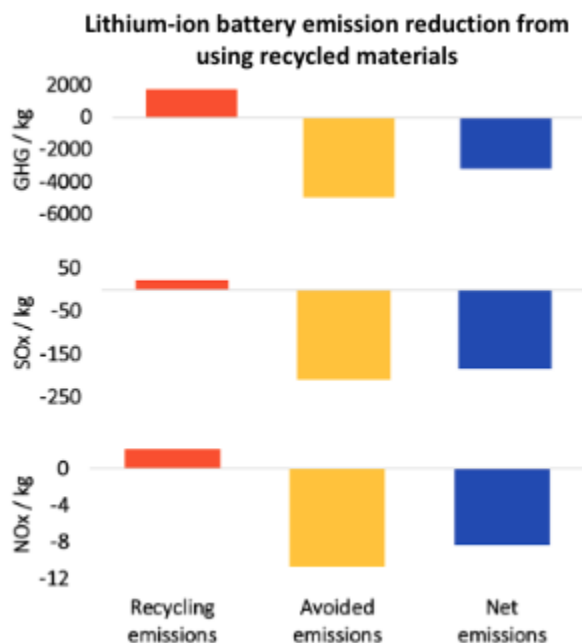
Scientists evaluating resource availability through mining typically look at [two categories](#): the total available resources and the reserves. This distinction is important because the reserves represent the global resources that are *economical* to extract, while the total resources represent an estimate of the *finite global resources*. Reserve estimations

are therefore much less than total resources and fluctuate based on material value, mineral exploration, and technological development.

Recycling has many benefits

Recycling can drastically decrease new mining needs and is an essential strategy to sustainable, secure, and affordable electrification.

How is recycling more sustainable? The environmental **impacts** from using recycled content are much lower than newly mined materials. Since the materials recovered through recycling were already in the economy, the only impacts associated with their production are from transporting the battery to recycling, pre-processing, and recycling. By using recycled instead of newly mined materials, reduction of climate-changing greenhouse gas emissions is approximately 64%. Emissions which create smog and impact human health can also be mitigated; sulfur oxides can be reduced by 89% and nitrogen oxides by 78%.



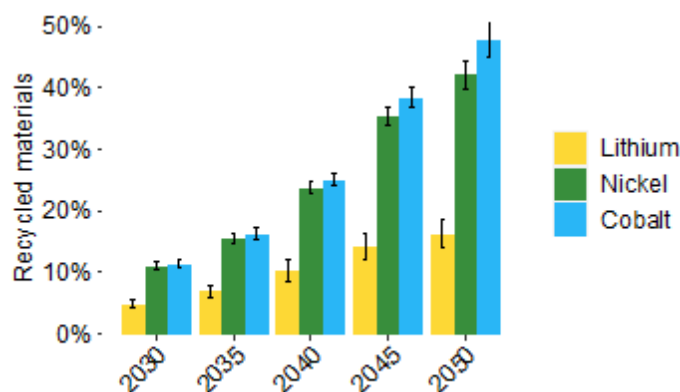
'Net emissions' represents the net emissions abated from using recycled instead of newly mined materials to manufacture 1kg of lithium-ion battery. 'Recycling emissions' represent the emissions from recycling using hydrometallurgical processing and 'avoided emissions' represent the total emissions that were abated by not

manufacturing a kg of battery from newly mined materials. Information for this figure was taken from [Dunn et al. \(2022\)](#).

Why is recycling an essential strategy to achieve secure and affordable electrification? In addition to comparing the available supply and demand, there are a lot of **other factors** that can lead to material shortages such as inadequate processing capacity and geopolitical supply chain issues. Recycling can secure a local supply of materials and decrease new material demand, all factors that can keep costs down.

How much demand can be met with recycled materials?

Estimates show that in the United States a large portion of future EV material demand can be met with recycled content. In 2050, recovered material can supply approximately 45–52% of cobalt, 40–46% of nickel, and 22–27% of lithium demand for EVs. In the short-term, recycled content will represent a smaller amount of battery materials—this grows as more material is in the economy and EV batteries retire.



The percent of EV battery material demand in the United States that is estimated to be able to be met by recycled materials. This can also be referred to as recycled content. Information for this figure was taken from [Dunn et al. \(2022\)](#).

Since mined materials will be needed to supplement recycled content, we need to ensure ethical and sustainable sourcing. In addition, it is essential that material demand is decreased through increasing the material efficiency of batteries and EVs and shifting away from car dependency and towards more public transportation.

Is recycling profitable?

While the exact economics of recycling facilities in operation are unknown, the plans for recycling facility expansion, along with recycling cost estimates using National Lab models, indicate lithium-ion battery recycling is (or soon will be) profitable. Since recycling is not a requirement in the US, current recycling is happening because of economics or funded research and development.

Recycling revenue is heavily influenced by the materials contained in the battery and their market value. Within a lithium-ion battery there is an anode, the negative electrode, and a cathode, the positive electrode. The battery charges and discharges by cycling lithium-ions between the anode and the cathode.

The materials used in the lithium-ion battery cathode vary. Until recently, most of the popular EVs contained a battery with cobalt and nickel because it enables them to have a long range in a compact size. [Tesla and Ford](#) are now transitioning towards a chemistry without cobalt for their lower range EVs, called lithium-iron phosphate (LFP). Nickel and cobalt are expensive materials and have some of the highest associated environmental and social impacts. Lessening the use of these materials is overall beneficial, but it also reduces the battery's worth to recyclers.

As cobalt and nickel are reduced in batteries (or phased out completely) recycling can still be done, but it may not be profitable with current recycling technology. Since recycling isn't a requirement, and the recycling occurring is mostly based on the positive economics, it is essential that policy is enacted to ensure all batteries are recycled, even if there are not high economic returns.

What does this mean for the long-term sourcing of materials for lithium-ion batteries?

There are enough materials to make EVs, but recycling is necessary to make them more sustainable, ethical, and affordable.

The switch from gasoline to electric presents a huge opportunity for efficient resource use. Unlike our current system, where we continually extract petroleum and burn it up in our cars and trucks adding to air pollution and climate change, the minerals we use to build EVs can be captured and reused to support the next generation of clean vehicles.

Currently, the United States doesn't require lithium-ion battery recycling, but we do know that recycling is occurring, thanks to [reports](#) by recyclers and contracts between automakers and recyclers. While this is a good indicator, a policy that requires and supports the recycling of EV batteries is still necessary to ensure as many batteries are recycled as possible, even if it isn't profitable.

EV battery recycling policy in the United States to-date consists of investment in recycling research, development, and demonstration, such as in the [Bipartisan Infrastructure Law](#). California, on the other hand, is more actively exploring recycling requirements. A group of stakeholders recently submitted [policy recommendations](#) to the legislature, including the requirement that automakers are responsible for the recycling of EV batteries when they are retired. An outline of their process and findings can be found in a recent [blog](#) of mine. We will be following the next legislative session closely with the hope that good policy is developed.

Posted in: [Transportation](#)

Tags: [climate-change](#), [critical materials](#), [electric vehicles](#), [Lithium-ion batteries](#)

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About the author

[MORE FROM JESSICA](#)

Jessica Dunn is a senior analyst in the Clean Transportation Program, specializing in lithium-ion battery sustainability. She conducts research on material circularity and reducing battery impacts through repurposing and recycling.

How Much Land Would it Require to Get Most of Our Electricity from Wind and Solar?

February 22, 2023 | 4:48 pm



Steve Clemmer
Director of Energy Research & Analysis

Critics of wind and solar routinely raise concerns about how much land would be required to decarbonize the US power sector. Fortunately, the answer is relatively little. A recent National Renewable Energy Laboratory (NREL) study shows that it would take less than 1 percent of the land in the Lower 48—that's an area comparable to or even smaller than the fossil fuel industry's current footprint. And when wind and solar projects are responsibly sited, the environmental and public health impacts would be far less harmful than those from extracting, producing and burning fossil fuels.

A key role for wind and solar

The fact that renewables will not require an inordinate amount of land is welcome news because limiting climate change's worst impacts will require us to cut global heat-trapping emissions roughly in half by 2030 and to achieve net-zero emissions by 2050, according to the [Intergovernmental Panel on Climate Change](#). Acknowledging that the United States is a leading contributor to carbon emissions, the Biden administration has committed to cutting US emissions 50 to 52 percent below 2005 levels by 2030. [Most studies](#) show that achieving these targets will require an unprecedented increase in wind and solar power to decarbonize the power sector and meet the increased demand for zero- carbon electricity to replace fossil fuels in building, industrial and transportation sectors.

A [2022 NREL study](#) found that, to achieve President Biden's goal of generating 80 percent zero-carbon electricity by 2030 and 100 percent by 2035, we will need to increase wind and solar power from about [14 percent](#) of the US electricity mix in 2022 to between 60 and 75 percent by 2035 under the main scenarios. When combined with modest increases in geothermal and hydropower capacity at existing unpowered dams and upgrades to existing facilities, renewable energy would provide 70 to 85 percent of total US electricity generation by 2035. NREL projects that most of the remaining generation would come from existing nuclear plants and a small amount from gas plants, carbon capture and storage, hydrogen and biogas.

NREL also found that meeting the growing demand for zero-carbon electricity means overall US generation capacity would need to roughly triple between 2020 and 2035, including a combined 2,000 gigawatts (GW) of wind and solar capacity. This would require growth rates in the range of 43 to 90 GW per year for solar and 70 to 145 GW per year for wind by the end of the decade, which would mean more than quadrupling the current annual deployment rates for each technology.

Although siting, permitting and ramping up manufacturing for all of this new wind and solar generation will be challenging in this time frame, NREL's study and other studies suggest that it is technically and economically feasible. For example, about 930 GW of wind and solar capacity and 420 GW of storage projects are now awaiting approval to connect to the transmission system, [according to Lawrence Berkeley National Lab](#). This year alone, developers are planning to install 29 GW of utility-scale solar. That's more than double the current record and represents more than half of all new US capacity, according to recent Energy Information Administration (EIA) [data](#). EIA also projects US battery storage capacity to more than double in 2023.

The federal Inflation Reduction Act (IRA) also will make a big difference by making available hundreds of billions of dollars in new incentives for these technologies. NREL's [2022 Standard Scenarios](#) study found that these federal incentives would accelerate the deployment of wind and solar, helping to reduce US power sector carbon dioxide emissions to 80 percent below 2005 levels by 2030.

Comparatively small footprint

NREL found that the land area directly occupied by wind and solar infrastructure by 2035 would make up less than 1 percent of the land in 94 percent of the country and less than or equal to 7 percent of total land area in just three states. A key reason why a relatively small amount of land is needed is because only 2 percent of the total area within a wind farm is occupied by wind infrastructure, while the remaining 98 percent is available for agriculture, grazing or other

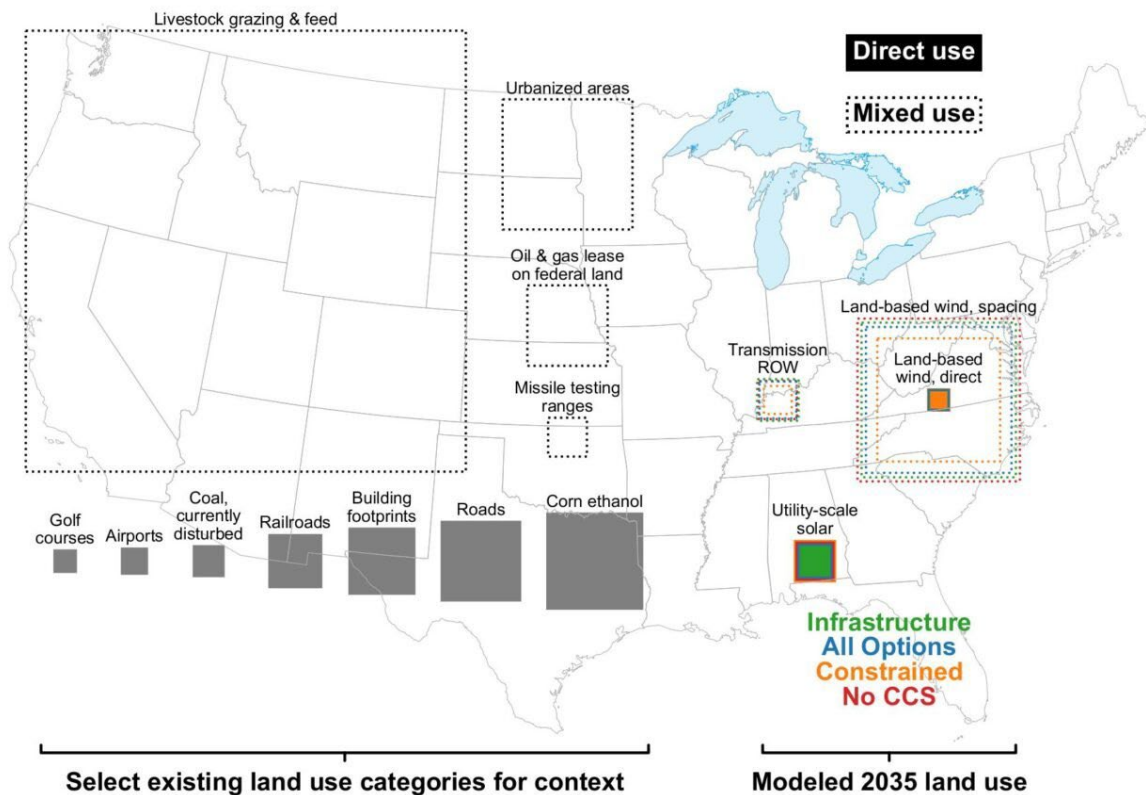
uses. Offshore wind turbines also have a relatively small footprint and are able to use much larger turbines than land-based projects. Rooftop solar deployment, meanwhile, doesn't require any land.

Of course, to deliver all this clean energy from wind-rich regions in the Midwest and Plains states to major load centers in the East will also require a lot of additional transmission lines. NREL found that total US transmission capacity would have to increase by 1.3 to 2.9 times current levels by 2035. This would require 1,400 to 10,100 miles of new high-capacity lines per year, assuming new construction began in 2026.

But the big news is NREL found that the total amount of land needed by 2035 to achieve our clean power goals with wind, solar and long-distance transmission lines (19,700 sq. mi) would be:

- equivalent to the land area currently occupied by railroads (18,500 sq. mi)
- less than half the area of active oil and gas leases (40,500 sq. mi)
- less than one-third of the area currently needed for ethanol production (59,500 sq. mi), and
- only slightly more than the historically disturbed land area for coal mining (13,100 sq. mi).

Plus, NREL's main "All Options" scenario projects roughly 250,000 wind turbines in the United States, which is considerably less than the nation's 1.5 million oil and gas wells.



Total area occupied by wind turbines and solar photovoltaic infrastructure (solid colored boxes) is roughly equal to the land occupied by railroads. (Map courtesy of NREL)

Environmental and public health benefits

Perhaps most important, though, is the fact that replacing fossil fuels with wind and solar will dramatically reduce the amount of land needed for mining, drilling, transporting, producing and using fossil fuels. Land used for these activities—and for disposing of coal ash and other wastes—often creates significant long-term environmental and public health problems for local communities.

By contrast, the land-use impacts of wind and solar projects tend to be short-term and reversible. As mentioned above, 98 percent of the land needed for a wind farm is available for agriculture, grazing or other productive uses. Co-located solar and agriculture, or “**agrivoltaic**,” systems can make agriculture more sustainable by improving both energy and food production. Utility-scale solar projects also can be

built on previously disturbed and contaminated land that was remediated for reuse, including brownfields, landfills, abandoned mine lands, invasive species-impacted land, gravel pits and quarries, Resource Conservation and Recovery Act and Superfund sites, and retired coal- and natural gas-power plant sites.

And, unlike fossil fuels, electricity generated by wind and solar does not use water or produce any emissions or wastes that can contaminate the air, land or waterways. When wind and solar projects reach the end of their useful lives, they can be removed and the land can be easily restored.

That said, mining some critical minerals for wind turbines, solar panels and batteries can have significant land-use impacts. Stringent policies and safeguards are needed to avoid, minimize and mitigate these impacts. Most of this mining currently occurs in other countries, but the IRA and the infrastructure law both include incentives to source more of these minerals domestically. In addition, several efforts are underway to recycle and reuse wind turbine components, solar panels and batteries instead of disposing them in landfills. (See more on these issues in these recent [UCS blogs](#)).

Responsible siting required

Transitioning to a clean energy economy that relies heavily on wind and solar is a big and vitally important undertaking. Minimizing land-use impacts will require responsible siting of wind and solar projects that avoids use of sensitive, or otherwise inappropriate, land and waters.

Fortunately, NREL's modeling takes much of this into account in its report and related [video](#):

- For wind power, NREL excludes protected land (such as state and national parks, conservation areas, and water bodies), urban areas, and mountainous or difficult terrain. It also considers state and county setbacks as well as height ordinances and

excludes land that conflicts with other existing infrastructure, such as buildings, roads, railroads and radar.

- For utility-scale solar, NREL also excludes “prime” or “important” cropland and farmland as designated by the US Department of Agriculture. It also limits potential new solar PV facilities to sites within 12.4 miles of existing transmission in most scenarios.

When these assumptions are taken into consideration, roughly 29 percent of the land in the Lower 48 is available for wind development and 39 percent could be used for solar development under most of NREL’s scenarios.

NREL doesn’t consider changes to land-use patterns, including climate change impacts on land availability. But its implications are clear and heartening: If we develop wind and solar production in a responsible and sustainable way, the land-use demands are manageable and the environmental, public health, and land-use benefits of replacing fossil fuels will be enormous.

Posted in: [Energy](#)

Tags: [clean energy](#), [Renewable energy](#), [renewable energy land use](#), [solar power](#), [wind power](#)

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About the author

[MORE FROM STEVE](#)

As director of energy research for the Union of Concerned Scientists’ Climate and Energy program, Steve Clemmer conducts research on the economic and environmental benefits of implementing renewable energy technologies and policies at the state and national levels.

Challenges and Opportunities in Mining Materials for Energy Storage Lithium-ion Batteries

December 22, 2022 | 8:02 am





Charlie Hoffs

Former Schneider Sustainable Energy Fellow

Batteries are key to enabling the renewable energy transition. When the sun isn't shining or the wind isn't blowing, [batteries](#) help store clean energy to continue supplying electricity to the grid and to customers consistently and reliably. Generating and storing clean energy is a lifeline for the planet's future; burning coal, oil, and gas fossil fuels causes [75% of greenhouse gas emissions](#). Fossil fuel

extraction not only ignites climate change, but [degrades land](#) and wildlife ecosystems, pollutes waterways, acidifies the oceans, exacerbates natural disasters, [expropriates Indigenous land](#), and leads to devastating [chronic health impacts](#) for fossil fuel industry workers and adjacent communities.

A fossil fuel energy grid extracts and expends finite resources. It is wasteful by design. By contrast, nearly every part of a renewable energy grid can be circular. Energy from the sun and wind never runs out and is used again and again. Rechargeable large-scale batteries can be charged with solar or wind power and cycled thousands of times in their lifetime. At end-of-life, the valuable metals in batteries can be recovered and reused.

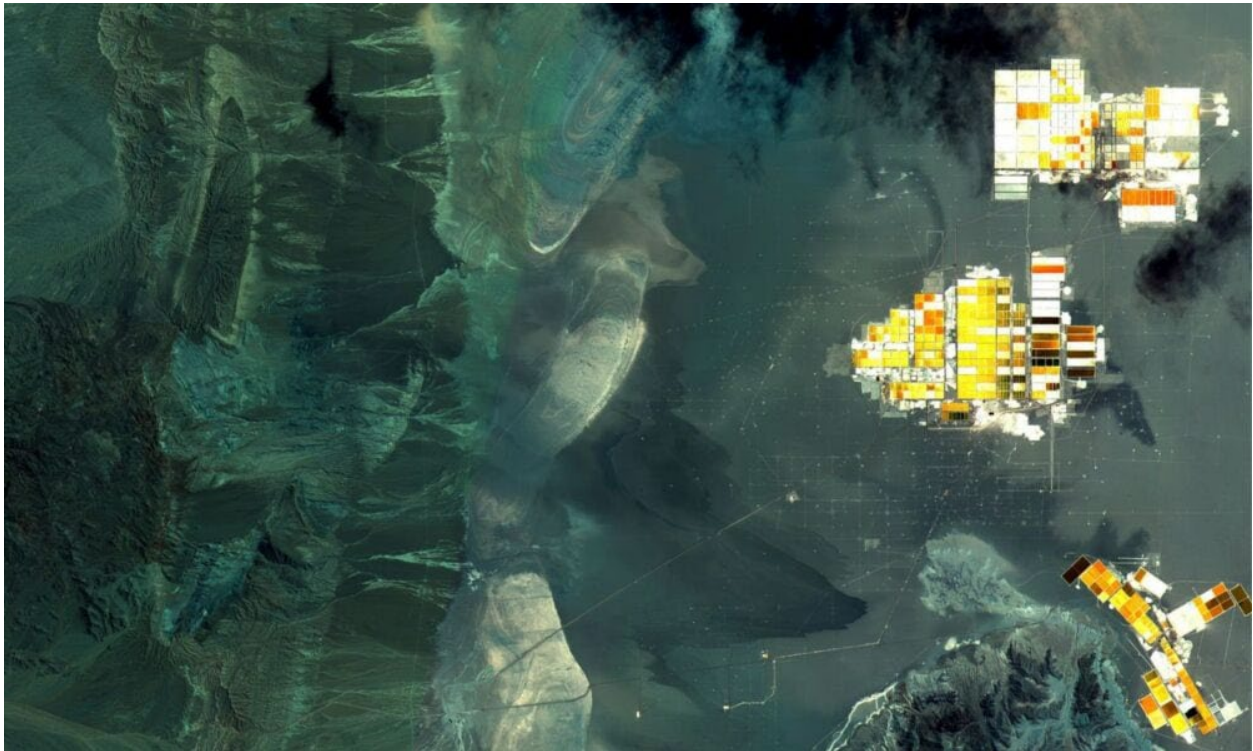
A circular battery life cycle is possible. More batteries are [being recycled](#) through [good policy](#), innovation, and corporate commitment. Public action and awareness-raising is bringing increased attention to the urgency of responsible sourcing.

This post takes a closer look at the supply chain of energy storage batteries from material mining to manufacturing. I explore solutions for more just, transparent, sustainable sourcing including ensuring materials are obtained with the [Free, Prior, and Informed Consent](#) of adjacent communities. I also explore alternatives like expanding production of and inventing new battery technologies with fewer critical minerals and reducing car usage by increasing public transit and walking through equitable urban planning. Our next [post](#) will then explore pathways to achieving a circular battery economy through battery repurposing and recycling.

While here I will focus on energy storage batteries for the power grid, electric vehicles—a much larger slice of the battery market—have very similar supply chains, manufacturing processes, and recycling infrastructure. Explore some of UCS's resources on electric vehicle (EV) battery recycling [here](#), [here](#), [here](#), [here](#) and [here](#).

Mining and manufacturing present challenges

There are seven main raw materials needed to make lithium-ion batteries. Among these, the US defines graphite, lithium, nickel, manganese, and cobalt as [critical minerals](#): metals of essential importance to US energy needs, but which have supply chains vulnerable to disruption. For lithium, cobalt, and nickel in particular, the battery industry drives global demand. Check out my [previous post](#) to understand how batteries use each of these materials.



Lithium mining via brine well water evaporation in the Atacama Salt Flat in Chile. Source: Coordenação-Geral de Observação da Terra/INPE/Flickr.

Lithium

At the center of attention in the battery world, lithium is a mighty metal spurring the global battery revolution. It is ideal for batteries in many ways because it is very light (made of merely 3 protons, 3 neutrons, and 4 electrons) and highly reactive, capable of storing lots of energy between its bonds. It is also rechargeable, and does not degrade significantly over [hundreds of recharges](#).

According to the US Geological Survey (USGS), global lithium consumption [increased](#) 33% from 2020 to 2021, due largely to battery

demand (for both EVs and the power sector). More than half (55%) of lithium comes from Australia, 26% from Chile, 14% from China, and 6% from Argentina.

Lithium extraction presents [challenges](#). In places such as [Argentina](#), [Chile](#), [Bolivia](#), [Serbia](#), and [the US](#), Indigenous and allied environmental justice advocates charge that lithium mining operations have accelerated drought, thus decreasing agricultural yields, local food security, and rural livelihoods. They also say mining has contaminated waterways and soil, led to police violence against mine protestors, and threatened sacred Indigenous sites.

A prospective new site in Southern California's [Salton Sea](#) could produce an estimated [20,000 metric tons](#) of lithium carbonate per year (for reference, global [production](#) in 2021 was 100,000 metric tons). While the site has the potential to use much less water and produce less waste than traditional lithium operations, [technical challenges](#) loom, and local residents of the 82% Latine Imperial Valley community are [concerned](#) that mining may exacerbate local [environmental](#) and [public health risks](#), without resolving pre-existing challenges of drought, toxic pollution, unemployment, and poverty.

In the scenario where humankind moves to 100% renewable energy by 2050, total [demand for lithium](#) for batteries from now until 2050 [could approach or significantly exceed](#) all known world reserves. ("[Reserves](#)" refers to how much mineral can currently be mined economically, not the estimated total amount of discovered and undiscovered minable lithium in the world, known as the total global resources.)

Lithium's supply and demand challenge offers an opportunity for recycling and reuse innovation to help sustain lithium availability responsibly into the clean energy future.

Cobalt

The name cobalt comes from "[kobold](#)," the German word for goblin. This is an appropriate moniker for a metal of almost mythical

importance to battery cathode production and that sometimes carries urgent environmental and social implications.

Global cobalt consumption [increased](#) 20% from 2020 to 2021 due to demand for EV batteries, which [can contain](#) up to 20 kilograms of cobalt per 100 kilowatt-hour (kWh) pack, the size of a [Tesla Model S](#) battery.



A cobalt mining pit in the Democratic Republic of Congo reaches down 90 feet. Source: Fairphone/Flickr.

A third of global cobalt is [used for EV batteries](#), and more than two-thirds of the world's cobalt [comes from](#) the Democratic Republic of Congo. A 2021 study by Bamana et al. reported that 15-20% of Congolese cobalt is sourced from 110,000 to 150,000 [artisanal, small-scale miners](#). The study documents how waste from the small mines and industrial cobalt mines can degrade the local environment and impact food security. Artisanal, small-scale miners have also been linked to human rights violations including [child labor](#), [residential displacement](#), and lack of humane work conditions and wages for miners.

In a scenario where the world achieves 100% renewable energy by 2050—and if lithium-ion batteries continue to rely on cobalt—[cumulative](#) demand (between now and 2050) for cobalt for batteries could [vastly exceed](#) all known world reserves.

But there is good news: most of the cobalt in a used battery can be successfully recovered and used to manufacture new batteries. In addition, battery manufacturers are working to reduce or remove cobalt from the next generation of lithium-ion batteries. Some EV companies, for example, are transitioning from “NMC111” batteries (containing nickel, manganese, and cobalt in a 1:1:1 ratio) to “NMC811” with a [fourth](#) or [fifth](#) as much cobalt. They're also adopting cobalt-free batteries such as LFP (containing a Lithium-Iron-Phosphate cathode). For example, half of all [Tesla vehicles](#) produced in the first three months of 2022 had LFP batteries. LFP batteries may overtake NMC in energy storage applications [by 2030](#) because they are more affordable, can have longer lifespans, and are less dependent on critical metals.

Nickel

The shift towards lower-cobalt batteries means more nickel is needed. Like cobalt, nickel (of “[Class 1](#)” 99.8% pure status) is a component of the metal-mix used in the cathode of batteries.



A Nornickel mine in Murmansk, Oblast, Russia. . *Source: Hans Olav Lien/Wikimedia Commons.*

Nickel sourcing is more geographically diverse than cobalt; 37% of [nickel comes from](#) Indonesia, 14% the Philippines, and 9% from Russia. Nickel mines can cause deforestation and water and soil contamination, such as in [Claver](#), Philippines. Mine pollution in Indonesia has severely impacted indigenous [fishing grounds](#), and state policies [repress activist protests](#). Indigenous Russian communities are [protesting Nornickel](#) for tailing leaks into waterways that are killing fish and endangering public health.

Meanwhile, a new company called Prony Resources in New Caledonia—a French territory with large nickel deposits—is majority owned by [tribal and local stakeholders](#) and may offer a more equitable [model](#) for stakeholder governance and mine co-ownership.



Prony Resource's Goro Nickel Mine in New Caledonia. Source: Barsamuphe/Flickr.

The International Energy Agency (IEA) projects that [nickel demand for EV batteries](#) will increase 41 times by 2040 under a 100% renewable energy scenario, and 140 times for energy storage batteries. Annual nickel demand for renewable energy applications is predicted to grow from 8% of total nickel usage in 2020 to 61% in 2040. Like cobalt, opportunities to reduce nickel demand lie in new battery chemistries and recycling.

Copper

Twenty-seven percent of [copper production](#) occurs in Chile, 10% in Peru, 8% in China, and 8% in the Democratic Republic of Congo. And 70% of the copper used in batteries is [already recycled](#). Researchers predict that the world will need to expand copper mining to meet the

future supply deficit. However, of the top [300 undeveloped copper orebodies in the world](#), 47% are located on or in Indigenous lands, 65% are in high water risk areas, and 65% are in or near biodiversity conservation areas.



Washing copper ore in the Democratic Republic of Congo. Source: Fairphone/Flickr.

Similar to other critical minerals, the copper industry—such as in [Chile](#) and [Peru](#)—can be connected to environmental, [labor](#), and public health problems that have incurred intense [community resistance](#).

To secure a just energy transition that contests, rather than deepens, oppression and extraction, mining projects must uphold environmental justice and human rights.

Graphite

Graphite makes up 95% of battery anodes. EV batteries can contain up to 280 pounds of graphite, over a quarter of their total weight. Demand for graphite in batteries is projected to grow by [30% each](#)

[year until 2030](#), and may constitute 8 to 25% of [global demand for graphite](#) by 2040. China produces 82% of the world's natural graphite (which is more commonly deployed than artificial or synthetic graphite). Intensive graphite mining in Heilongjiang and Shandong provinces in China [releases soot particulates](#) into the air that damage crops, coat homes in a layer of dark powder, and contribute to heart and lung disease.

As advocates push for just graphite mining regulation and transparency, companies are innovating [new circular economy technologies](#) capable of recovering battery-grade graphite from used batteries and other materials, and doing so without the use of corrosive chemicals.

Other battery materials

The lithium-ion battery industry also uses a very small portion of global manganese, iron, phosphorous, and aluminum supplies. While small in volume, ensuring these battery material supply chains are just and sustainable is also important. In particular, manganese mining, sometimes undertaken without community compensation nor consent, has been linked with toxic contamination and chronic illness in [Ukraine](#), [South Africa](#), and [Guyana](#). Iron ore mining, which releases large amounts of [emissions](#), has resulted in devastating mine waste leaks causing water contamination and [hundreds of fatalities](#). Across all mining sectors, government and industry commitments to just mining policy and a transparent circular economy is critical.

Manufacturing

After the raw materials are extracted, they must be refined and processed for use in batteries. China [processes](#) 72% of the world's cobalt, 61% of lithium, and 95% of manganese, while Russia leads in nickel processing.

China also leads in lithium-ion battery cell manufacturing. The country [has invested](#) over \$60 billion in this industry, and produced 80% of the world's cells. While the US currently produces 13% of global cells (about 520 gigawatt hours per year, mostly in Tesla-

Panasonic plants in Nevada), production is projected to increase due to [significant investments](#) within the Bipartisan Infrastructure Law and the [Inflation Reduction Act](#).

Can battery manufacturing be more responsible and sustainable?

Yes, and the industry can and must get there.

Lithium-ion batteries—many for grid energy storage, and many more for electric vehicles—play an important role in the clean energy future. They not only store renewable energy for the grid, but also power electric vehicles, which have significantly lower environmental impacts than gasoline cars. The average electric vehicle in the US emits 52% [fewer greenhouse gas emissions](#) over its lifetime than the average gasoline vehicle (which burns about 4,500 gallons of [gasoline](#) over its lifetime). The average EV's emissions are equal to a gasoline vehicle getting [91 miles per gallon](#).

To ensure the transition to a more battery-powered future is equitable and effective, energy storage and vehicle battery supply chains must be just and sustainable.

Here are four strategies government and business decisionmakers can use to improve lithium-ion battery materials sourcing and manufacturing:

- **Require ethical, sustainable sourcing and strong supply chain [standards](#).** Companies and organizations can join the [Global Battery Alliance](#) and the [Initiative for Responsible Mining Assurance](#). Industry leaders can actively respond to journalists and researchers from groups like the [Business & Human Rights Resource Centre](#), and ensure upstream critical minerals suppliers obtain the [Free, Prior, and Informed Consent](#) of the communities near which they operate. The US could consider implementing binding rules on more just and sustainable mining, including considering reforms to the outdated [1872 Mining Law](#), which still governs hardrock

mining 150 years later. The US could also consider [rejoining](#) the Extractive Industries Transparency Initiative (EITI), a coalition of over 50 countries dedicated to increasing just and environmentally friendly sourcing.

- **Produce batteries with reduced reliance on high impact critical minerals.** Policymakers and companies can accelerate the transition to batteries that use materials with lower environmental and social impacts. LFP batteries, for example, result in lower impacts because they contain no cobalt nor nickel.
- **Support development of new battery technologies for energy storage.** New solid-state, sodium-ion, and redox-flow batteries, along with other [innovations](#), may offer more affordable, secure, long-duration, and critical-metal-free options for energy storage.
- **Invest in infrastructure and urban planning solutions that increase public transit usage, walking, and biking.** While accelerating the transition from internal combustion engine vehicles to electric vehicles is an urgent priority, the most effective strategy for reducing US car emissions—and the impacts of battery critical metal mining—is reducing car ownership and usage overall. Governments must undertake the difficult and essential work of building accessible, affordable, efficient public transportation systems, and built environments that encourage biking and walking.

Fleets of batteries—acres and acres of unassuming stationary metal boxes—are a key to unlocking the [renewable energy future](#). But are batteries, themselves, renewable? Can they be reused or [recycled](#) at the end of their life? Where do their [raw materials](#) come from, and how can we ensure their valuable contents are recovered rather than wasted? [Click to learn more!](#)

[How are Lithium-ion Batteries that Store Solar and Wind Power Made?](#)

[Want Clean Energy? Then You Also Want Battery Recycling.](#)

And what about the solar panels and wind turbines, which generate the electricity that batteries store? Check out our previous [posts](#) on solar panel and wind turbine life cycles!

Editors note (1/4/23): Following feedback from colleagues in the mining justice sector, we've made edits to better reflect equitable, effective strategies for mining reform and advocacy.

PART OF A SERIES ON **Recycling Clean Energy Technologies**

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About the author

[MORE FROM CHARLIE](#)

Charlie Hoffs served as a 2022 UCS Summer Schneider Fellow in Cambridge, Massachusetts. She earned her BS Chemical Engineering from Stanford University in 2022, and is currently pursuing an MS in Community Health and Prevention Research at Stanford. In April 2020, she co-founded and continues to co-lead unBox, a youth-led organization working to unite and empower young people to fight US food insecurity.

What Happens to Wind Turbine Blades at the End of Their Life Cycle?

December 12, 2022 | 12:02 pm



Charlie Hoffs

Former Schneider Sustainable Energy Fellow

Perched atop towers hundreds of feet tall, overlooking grassy plains or windy seas, sleek white blades trace slow powerful circles through the

air. Can the life cycle of [wind turbine blades](#), lasting about 25 years, be as circular as the elegant arcs they carve in the sky?

This post will follow the wind turbine blade from “cradle-to-grave,” then explore solutions for a more responsible, sustainable life cycle. To learn about the current lifecycle and a more sustainable solution for the rare earth elements in wind turbine generators, read [How Are Wind Turbines Made?](#)

Blade materials are special

A [wind turbine includes](#) a foundation, a tower, electrical wiring, a nacelle between the blades, and the blades themselves. The [raw materials](#) used in the foundation and tower (steel and concrete) and wiring (copper and aluminum) are relatively inexpensive, and the wind industry uses a small fraction of global demand for these materials.

Wind turbine blades are a different story. Blades are made mainly of carbon fiber, fiberglass, and balsa wood and the wind industry drives a significant portion of global demand for these materials: 10% of [world demand](#) for fiberglass and 24% for carbon fiber come from wind turbines. While today’s carbon fiber and fiberglass require lots of [energy to produce](#) and are [hard to recycle](#), incorporating more bio-materials into their composites and developing new recycling technologies can reduce their footprint. Also, fortunately, the fibers and epoxies needed to make these strong synthetic materials are widely available.

The supply of balsa wood, on the other hand, is highly concentrated in Ecuador and Peru. The high demand for balsa wood in blades for lightweight structural support has linked the wind industry’s [demand](#) to increased Amazon rainforest logging and balsa plantation farming. By 2020, demand for balsa wood [outstripped supply](#). Legal and illegal balsa exports have transformed forest landscapes near [Indigenous communities](#) with limited consultation or consent of those affected communities.



Balsa wood logging. Source: Firdaus Latif/Wikimedia Commons

To ensure the wind industry upholds environmental justice and stewards its raw materials, many companies are replacing balsa with other materials. For example, [LM Wind Power](#) has minimized balsa in its blades, substituting in synthetic plastic PET and PVC foams. Additionally, INCA Renewtech invented BioBalsa, a durable blade material made of [hemp hurd cellulose](#). The energy research firm Wood Mackenzie estimates that the number of blades using PET as their core material instead of balsa will [increase](#) from 20% in 2018 to 55% in 2023.

Can wind turbine blades be recycled?

Yes! The good news is the steel, iron, aluminum, copper, concrete, and electronic components of wind turbine foundations, towers, and wiring can be completely recycled. Recycling the blades is a greater challenge, but an important one to overcome.

In 2021 in the US, [8,000 blades](#)—which each average about 200 feet—were retired. By 2050, the world may be getting 15-18% of its energy from wind, but may also have [43 million metric tons](#) of retired blades to address. Although [landfilling of blades](#) does not pose a threat of soil or groundwater contamination and would represent only a tiny fraction of global solid waste streams, the lifecycle of wind turbines would be more circular if there were more options to reuse or recycle the blades.

Composite materials like fiberglass and carbon fiber are tricky to break down, precisely because they are *composite*, finely blended mixes of different materials which must be separated to be recycled. Those composites make blades hardy and durable, resisting wear and tear for decades.

While today, many retired wind turbine blades end up in [landfills](#), innovative companies have developed repurposing and recycling technologies to help avoid that fate. [Veolia](#), partnering with GE, can shred down fiberglass blades and turn them into cement. Carbon Rivers can transform fiberglass blades into textiles and other synthetic materials, while [Global Fiberglass Solutions](#) turns recycled fiberglass into railroad ties and plastic pellets. Vestas and a network of partners have developed the [CETEC plan](#) (Circular Economy for Thermosets Epoxy Composites), which in the next three years will be able to separate blade fibers from epoxy and use the epoxy in new blades.



An onshore wind turbine being transported to Muirhall Wind Farm in the UK. Source: ShellASP/Wikimedia Commons

Companies have also started to develop new, more recyclable blade technologies which continue to guarantee strength while facilitating end-of-life processing. For example, [Siemens Gamesa](#) installed the first ever recyclable wind turbine blade at an offshore wind farm in Germany in July 2022. It employs a new type of blade epoxy resin. When the blade is immersed in an acidic fluid at high temperatures, the resin dissolves and the components separate, becoming recyclable. The company aims to make all its blades fully recyclable by 2030.

Responsible, circular solutions for wind turbine blades

All wind energy stakeholders, including states, the federal government, companies, suppliers, and consumers, can fuel the responsible, sustainable development of a circular wind energy industry. Some strategies include:

1. **Ensure an ethical, sustainable supply of balsa wood.** Companies can work with their balsa wood suppliers to ensure their materials are sustainably and ethically sourced, and that [free, prior, and informed consent](#) of logging- and plantation-adjacent communities is ensured. Governments can support research into, and companies can experiment with, new substitute materials for balsa wood in wind turbines.
2. **Hold companies accountable for end-of-life management.** Extended producer responsibility (EPR) is a proposed concept in which technology companies must plan, execute, and pay for their product's end-of-life processing through reuse or recycling. The EU has [implemented](#) such policies for batteries and solar panels, and governments around the world can follow this model for wind turbine blades. They can also reward companies that recycle their blades through incentives.
3. **Accelerate the use of recycled materials in new blades.** To create a [circular economy](#) for recycled blades, there must be a market. Blade manufacturers must establish contracts with today's nascent blade recyclers to speed up the transition to using recycled materials in new blades.
4. **Increase recyclable blade research and development.** States and the federal government can provide competitive grants, research funding, and incentives to labs and companies innovating new recyclable blade chemistries.

When we think about wind turbines, we visualize big circles high in the sky. The wind turbine blade life cycle can be just as circular. Governments, industry, and consumer commitments are moving us towards even more responsible, sustainable blade supply chains and end-of-life management.

How are wind turbines made? What happens when wind turbines reach the end of their service lifetimes? What will it take to ensure those colossal, majestic blades don't end up in landfills? Where do their raw materials come from, and when they retire, can we process those materials into other

useful products or recycled blades? How can we move towards a sustainable, responsible wind energy supply chain, and ensure all materials come “full circle”? Click the links below for answers:

[*How Are Wind Turbines Made*](#)

[*Just and Sustainable Solutions for the Mining and Recycling of Rare Earth Elements in Wind Turbines*](#)

Now that you’ve learned about wind power, are you interested in the life cycle of solar panels? Read on:

[*How Are Solar Panels Made?*](#)

[*Mining Raw Materials for Solar Panels: Problems and Solutions*](#)

[*Solar Panels Should Be Reused and Recycled. Here’s How.*](#)

PART OF A SERIES ON **Recycling Clean Energy Technologies**

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About the author

[MORE FROM CHARLIE](#)

Charlie Hoffs served as a 2022 UCS Summer Schneider Fellow in Cambridge, Massachusetts. She earned her BS Chemical Engineering from Stanford University in 2022, and is currently pursuing an MS in Community Health and Prevention Research at Stanford. In April 2020, she co-founded and continues to co-lead unBox, a youth-led organization working to unite and empower young people to fight US food insecurity.

Solar Panels Should Be Reused and Recycled. Here's How.

October 19, 2022 | 12:39 pm



Charlie Hoffs

Former Schneider Sustainable Energy Fellow

Picture this: Light energy from the sun zooms through the solar system to reach your sunny rooftop, gets absorbed into your solar panel, and charges the device or computer on which you are reading

this post. It is a perfectly closed, sustainable system. Can the life cycle of a solar panel itself be just as circular?

Today, unfortunately, the life cycle of a solar panel is not yet a “cycle.”

It is more like a straight line from silica mine, to refining factory, to shimmering batch of shining polysilicon ingots, to [panel assembly](#), to a couple decades generating clean electricity—and then, far too often, to a landfill.

Only [10%](#) of solar photovoltaic, or PV, panels are recycled today in the US, and the rest meet their inglorious end in the garbage heap. Among those that are recycled, very few have 100% of their material recovered. There is presently no federal law or regulation regarding residential or utility-scale solar panel reuse or end-of-life management.

But there is hopeful progress in state policy, business and research innovation, and nonprofit solutions. This post explores current case studies of responsible, sustainable end-of-life solutions, and makes recommendations for future circular solar supply chains.

Meet today's end-of-life solar leaders

Several states have pioneered innovative public policy to recycle and repurpose retired residential and commercial solar panels. For example, the state of Washington [requires](#) photovoltaic module manufacturers either take back and reuse or recycle modules at no cost to owners. New Jersey has formed a [commission](#) to create recommendations for solar panel recycling, and North Carolina [directed](#) their Department of Environmental Quality to adopt rules for governing panels' end-of-life management in utility-scale projects. Meanwhile, a California [law](#) reclassified PV modules as “universal waste” as opposed to “hazardous waste,” which involves less stringent handling regulations.

In the for-profit and nonprofit sectors, several companies and organizations lead the solar panel reuse and recycling transition. US company First Solar can [recover 90%](#) of its panel's materials (which

are cadmium telluride, not crystalline silicon). [Good Sun](#) is a nonprofit organization based in California that sells used solar panels for a discounted price for installation in low-income US communities. And Solarcycle [aims to recycle](#) up to 95% of panel materials, including the difficult-to-extract [silver, copper, and silicon](#), via an electrostatic separations process that separates these particles by mass and electrical properties.





German company SolarWorld recycling decades-old solar panels. Photo credit: Spot Us/Flickr.

What solutions exist for a more circular end-of-life?

While promising legislation and private and nonprofit sector efforts are leading the way towards a more circular solar supply chain in the US, much more acceleration of reuse and recycling is needed. The myriad challenges involved in [mining and manufacturing](#) solar panels add to the reasons why the industry must increase its reuse and recycling of used panels. There are many paths forward for ensuring that the lifecycle of a solar panel is circular not linear. Here are two:

1. Use regulation to increase solar panel reuse.

Like driving a car more than 200,000 miles to its very last sputter, extending the life of a solar panel should be the first obvious solution. Solar panels should be used as long as possible. They do, however, lose some of their generating capacity over time.

An [analysis](#) by the Harvard Business Review predicts that those capacity decreases, along with cheaper and better panels coming on the market, may incentivize solar customers to discard their old panels early, and buy new ones. If too many consumers choose to get rid of their panels in 10-15 years as opposed to 30 years, discarded panels could outnumber new panels installed by 2.5 times in 2035, compounding the need for increased reuse solutions.

Early retired solar panels usually retain 70-90% of their original capacity. However, few solar manufacturers currently invest in the repairs to prepare panels for secondary life resale because repair costs often exceed resale profits. But there is a way through this problem.

The EU requires manufacturers to handle the reuse and recycling of solar panels with no cost to consumers. The US could create similar rules here. This would incentivize companies to provide additional refurbishing, life-extending services to their customers. Governments can also provide tax credits for companies providing robust repair and refurbishing services that extend client usage. To boost the secondary sale of good-condition solar panels for reuse, the US could also enact a nationwide standard that facilitates labeling and diagnostics of the quality of used PVs, so producers and buyers can better assess their price, value, and safety.

Manufacturers have a responsibility here, too; they can design panels with reuse in mind and facilitate parts disassembly and refurbishing for resale. States and the federal government can enact policies to reduce the regulatory burden and liability associated with reuse.

2. Boost the solar panel recycling industry.

Governments and the panel manufacturing industry can create a robust system for solar panel recycling. Effective solar panel recycling necessitates policy enactments at the state and federal levels and increasing the recycling market so that the cost of recycling per panel is less than the cost of sending it to a landfill.

According to the National Renewable Energy Laboratory (NREL), recycling a solar panel in the US can cost \$15-45, while sending a panel to the landfill costs only \$1-5. In the EU, on the other hand, recycling costs \$0.75 per panel because of mandates requiring manufacturers pay into a fund that subsidizes recycling. Consequently, in the EU, solar recycling rates reach 95%.

Additionally, US consumers need more information from manufacturers on the cost and value of recycling and reusing their PV panels. Manufacturers and secondary buyers should have open access to reliable data on the cost-benefit of different end-of-life options.

The federal government has a role to play, too. It could invest in research to optimize cost-effective recycling that processes the majority of the solar panel.

Lastly, and crucially importantly, solar panels must be recycled safely, sustainably, and ethically, both in the US and abroad. Corporate commitment and government regulation can help ensure that the solar industry upholds stringent labor and environmental standards, as some general e-waste industry operations continue to endanger recycling worker health and safety.

The path forward

We all want the most sustainable, responsibly sourced solar panels on our rooftops and in our communities. Governments, businesses, and consumers are increasingly committed to achieving that goal. Supply chain and end-of-life challenges also present opportunities for better circular innovation and stewardship as we move into the clean energy future.

Want to learn more about how solar panels are made and the solar panel supply chain? Which countries are driving PV material mining and PV manufacturing? Click the links for answers:

[How Are Solar Panels Made?](#)

[Mining Raw Materials for Solar Panels: Problems and Solutions](#)

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BUILDING A SUSTAINABLE MINERAL SUPPLY CHAIN FOR A CLEAN ENERGY ECONOMY

To avoid the worst effects of the climate crisis, we must swiftly ramp down our reliance on fossil fuels and transition to clean energy. But we have the opportunity to do what the fossil fuel industry never did—to protect the communities and environments impacted by energy development. The transition to clean energy will require more of certain types of minerals to build the solar panels, batteries, and other clean energy technologies of the future. These minerals, including lithium and cobalt, are often referred to as “critical minerals.” The current policies we have in place are not sufficient to ensure we have a truly sustainable supply chain that protects communities from the impacts of mining and extraction.

A just transition should not come at the expense of communities or the environment. This threat is real: According to EPA, hardrock mining is the country’s most toxic industry. Tribes and communities across the country are worried about the impacts of mining near their homes, schools, and sacred places. For example, the Hualapai Tribe are fighting the Big Sandy lithium project in Arizona, which threatens their sacred spring.

It is imperative that we protect communities that could be harmed by critical minerals mining and development by providing sufficient protections for the environment, health, and cultural resources, and by creating a more sustainable supply chain for the products we use to make and store clean energy. We can’t move energy “sacrifice zones”—where people bear the brunt of the impact—from oil-and-gas-impacted communities to mining-impacted communities.

Ways to Create a Sustainable Clean Energy Supply Chain:

- **Reforming Domestic Mining Law:** Mining in the United States is currently governed by a more than 150-year old law. Updating this outdated law for the 21st century can provide protections to communities, lands, waters, and cultural resources while also ensuring community input is robust from the outset of a mining project, which will reduce permitting delays and uncertainty. Legislation like the Clean Energy Minerals Reform Act and ensuring Free, Prior, and Informed Consent (FPIC) would do just that.
 - **Setting Standards for Domestic and Imported Minerals:** If we want other countries to have strong labor and environmental standards for mining, the U.S. must lead by example and implement high standards for itself, as well as negotiate high standards in trade agreements—including through verifications and certifications like the Institute for Responsible Mining Assurance (IRMA).
 - **Employing a Precautionary Approach to Deep Seabed Mining:** The exploitation of the deep sea for critical minerals poses unknown risk to the ocean, climate, fisheries, biodiversity, and the people, economies, and communities that depend on the ocean. We must protect these ecosystems and resources for generations to come.
 - **Creating the Circular Economy:** We must meet the demand for critical minerals in the most sustainable way possible: by recycling, reusing, and extending the life of materials and products we already have. The U.S. is behind our international partners on the creation of a circular economy for our minerals. A more sustainable supply chain will ensure we have an adequate supply of products necessary for an equitable transition by reducing the need for virgin material.
-

How We Jumpstart our Circular Economy:

- **Federal Government Leadership:** Build on language in the 2023 National Defense Authorization Act to establish a recycling program within the federal government, including the Department of Defense, to show leadership by example, and create a market. This should include both electronics and the federal fleet of vehicles.
- **Recycled Content Requirement:** Require all purchasers of critical materials and producers (clean energy manufacturers, car manufacturers, etc.) to purchase or use a certain percentage of critical materials from recycled sources. In the EU, a recycled content requirement will go into effect for electric vehicle batteries in 2026.
- **Domestic Battery Labeling:** Require all batteries manufactured or sold in the United States to be labeled with sourcing data and other important information. This enables consumers and recyclers to identify the source of the critical materials used, the percentage of the critical materials that were sourced from recycled content, and other key environmental and social factors. One way to do this is through a digital identifier or “Battery Passport,” which will be required for EV batteries under the EU battery regulation.
- **Tax Incentives:** Tax credits could be established for entities such as waste recyclers for recycling qualified electronic waste, companies for building responsible recycling facilities, or manufacturers for reducing the use of virgin critical minerals.
- **Certification Program/Consumer Education:** EPA can establish a certification program, modeled after the Energy Star program, that will give recognition to batteries and other renewable energy products made with the highest environmental, human rights, and labor standards. Such a certification program should also recognize, and thus incentivize, high percentages of recycled materials.
- **Producer Responsibility Model:** Extended producer responsibility is defined as “an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of a product’s life cycle” by the OECD. Following the example of the European Union, the U.S. can put the onus on producers to collect and recycle products at end-of-life.

FOR MORE INFORMATION CONTACT:

Blaine Miller-McFeeley, Senior Legislative Representative
bmcfeeley@earthjustice.org



Scan this code
to learn more

Electric Vehicle Factsheet



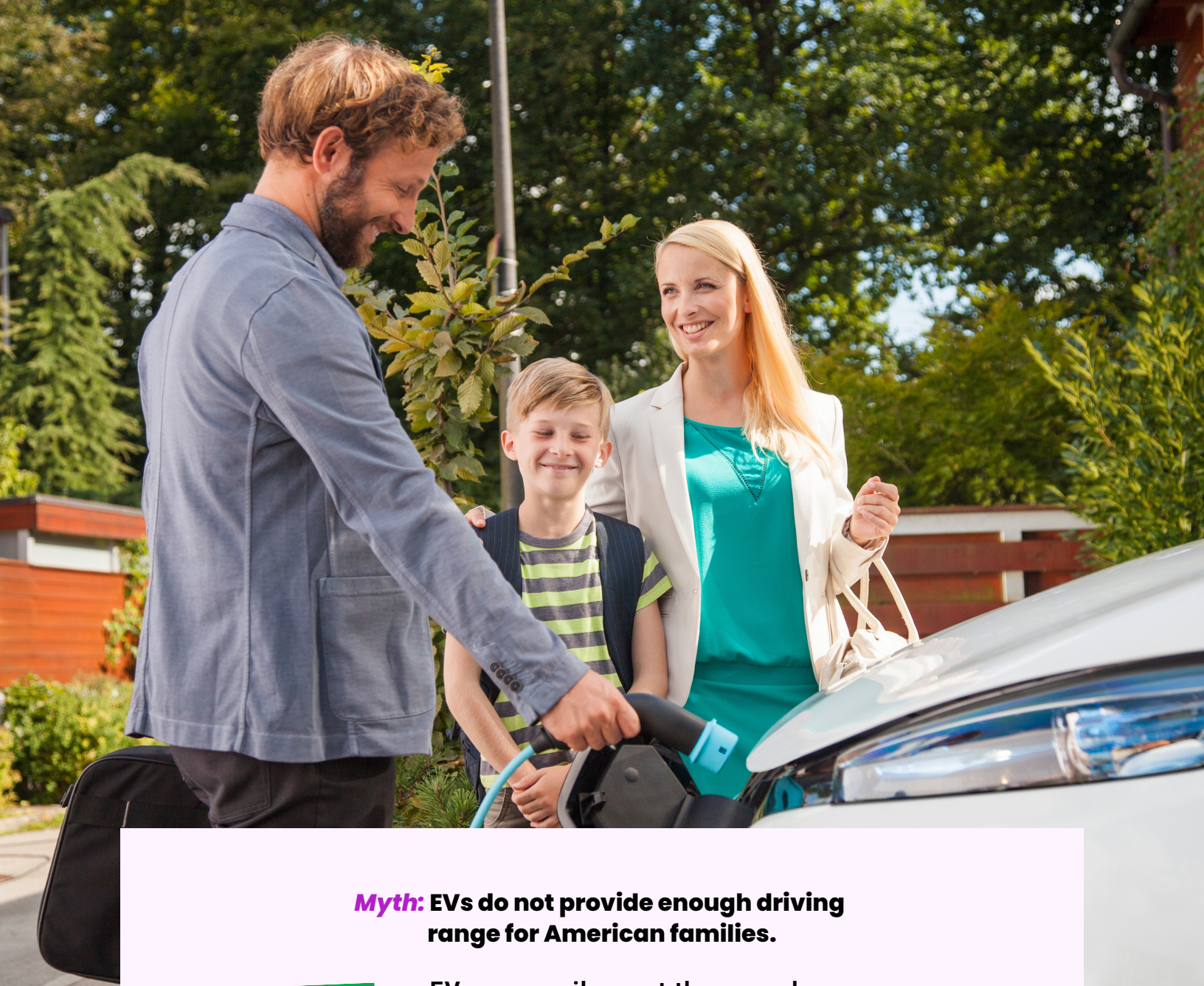
Myth: EVs are too expensive.

The Truth:

There are many models on the market today that are below or equal to the cost of an equivalent gas-powered car.¹

Recently passed tax credits will help make EVs more affordable, while drivers continue to experience significant savings due to lower maintenance and charging costs.

- Many EVs cost less than the average price of a new gas-powered vehicle.²
- The purchase price of EVs is expected to reach parity with new internal combustion engine vehicles (ICEVs) in the mid-2020s.³
- EVs typically cost less over their lifetime due to lower maintenance and fueling costs.⁴
- Drivers can receive \$6,000–\$10,000 in total cost of ownership savings by driving an EV.⁵
- On average, EVs can cost the equivalent of \$2 a gallon or less to charge.⁶ EVs provide American families with protection from fluctuations in oil prices caused by foreign governments and international conflicts.⁷
- EVs will become even more accessible to American families as the used-car market grows - more than 70% of car sales in the U.S. are pre-owned vehicles.⁸
- The Inflation Reduction Act includes several tax credits to help Americans afford EVs, including credits for new, American-made vehicles (section 30D) and used vehicles (section 25E).⁹



Myth: EVs do not provide enough driving range for American families.

The Truth:

EVs can easily meet the everyday transportation needs of American drivers.

- There are many EVs that provide more than 200 miles of range per charge, and at least 18 models that have driving ranges above 300 miles.¹⁰
- The average American only traveled 39 miles per day in 2019 (pre-COVID);¹¹ rural Americans traveled further at 48.6 miles per day.¹²
- Access to public charging stations is expected to increase with the launch of the NEVI program, which aims to place EV charging stations at least every 50 miles along our nation's highways.¹³



Myth: EVs are not made in America and will take away American jobs

The Truth:

The EV industry is creating thousands of good-paying jobs around the country. Recent eligibility requirements for tax credits will provide new opportunities for workers across the country.

- Nearly 340,000 Americans already work in the domestic clean vehicle sector.¹⁴ This number is estimated to rise above two million by 2035.¹⁵
- EVs account for three of the top five highest-scoring cars on Cars.com's 2022 American-Made Index.¹⁶
- Public investment through the Inflation Reduction Act and the Infrastructure Investment and Jobs Act will further grow domestic supply chains, including through funding critical minerals and battery production. This is in addition to research, development, and demonstration of new technologies, and the physical process of car manufacturing.¹⁷
- Recently, the Department of Energy announced \$2.8 billion in grants as a result of the bipartisan infrastructure bill. The grants were distributed to 20 companies working in 12 states to support the development of the domestic EV supply chain.¹⁸
- The Defense Production Act has been used to increase the nation's ability to produce critical minerals for EV batteries.¹⁹
- Meanwhile, the private sector is expected to invest \$1.2 trillion worldwide through 2030.²⁰
- More than \$700 million in private investment has already been announced to manufacture more than 250,000 new EV chargers in the U.S alone.²¹



Myth: EVs are a fire hazard and put firefighters, individuals, and infrastructure at risk

The Truth:

EVs have been shown to be as safe, or even safer, than conventional vehicles.

- All EVs must meet the same Federal Motor Vehicle Safety Standards used by gas-powered vehicles.²²
- EV battery packs have extensive safety testing standards and are designed to shut down when a collision or short circuit is detected.
- Injury claims for EV drivers and passengers were more than 40 percent lower than that of identical gas-powered vehicles between 2011-2019.²³



Myth: EVs are not environmentally friendly

The Truth:

Regardless of where they are charged, EVs are cleaner when compared to internal combustion engine vehicles. As the U.S. energy grid moves toward more renewable energy sources, EVs will become even cleaner over time, especially when compared to internal combustion engine vehicles and the fossil fuel-based infrastructure that supports them.

- Transportation is the largest carbon-emitting sector in the United States and is responsible for one-third of our total carbon emissions.²⁴
- An overwhelming amount of research has found that EVs release lower emissions per mile over the lifetime of the vehicle, regardless of how their electricity was sourced from the grid.²⁵
- A 2022 study by the Ford Motor Company and University of Michigan researchers found that light-duty EVs can lower vehicle lifetime emissions by as much as 64% compared to gas-powered vehicles.²⁶
- Achieving 100% EV sales by 2030 and a cleaner grid would prevent \$1.3 trillion in health and environmental costs in the coming decades.²⁷

Related ZETA Publications



ZETA-EF releases independent research and in-depth analysis on policy proposals and their impact on EV adoption. Access these resources and more at:

<https://www.zeta2030.org/education-fund/resources>.

1. <https://www.cars.com/articles/here-are-the-11-cheapest-electric-vehicles-you-can-buy-439849/>
2. <https://www.foxnews.com/auto/electric-vehicles-cheaper-gas>
3. <https://www.edf.org/sites/default/files/documents/TransportationWhitePaper.pdf>
4. <https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf>
5. <https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf>
6. <https://www.nerdwallet.com/article/loans/auto-loans/cost-to-fill-up-ev>
7. <https://www.eia.gov/energyexplained/gasoline/price-fluctuations.php>
8. <https://www.statista.com/statistics/183713/value-of-us-passenger-car-sales-and-leases-since-1990/>
9. <https://home.treasury.gov/system/files/136/EV-Tax-Credit-FAQs.pdf>
10. <https://www.caranddriver.com/shopping-advice/g32634624/ev-longest-driving-range/>; <https://www.edmunds.com/car-news/electric-car-range-and-consumption-epa-vs-edmunds.html>
11. <https://www.kbb.com/car-advice/average-miles-driven-per-year/>
12. <https://www.zeta2030.org/white-paper-the-next-ev-market-expanding-electrification-in-rural-america>
13. <https://www.cnn.com/2022/09/27/ev-charging-stations-on-highways-dot-approves-50-states-plans.html>
14. <https://e2.org/reports/clean-jobs-america-2022/>
15. https://energyinnovation.org/wp-content/uploads/2021/04/Energy-Innovation_2035-2.0-Accelerating-Clean-Transportation-Policy-Report.pdf
16. <https://www.cars.com/american-made-index/>
17. <https://www.brookings.edu/research/will-the-infrastructure-law-and-inflation-reduction-act-transform-american-transportation-its-complicated/>
18. <https://www.nytimes.com/2022/10/19/business/electric-vehicles-republicans-investment-south.html>; <https://www.whitehouse.gov/briefing-room/statements-releases/2022/10/19/fact-sheet-biden-harris-administration-driving-u-s-battery-manufacturing-and-good-paying-jobs/>
19. <https://www.axios.com/2022/06/28/biden-ev-charging-investments>
20. <https://www.reuters.com/technology/exclusive-automakers-double-spending-evs-batteries-12-trillion-by-2030-2022-10-21/>
21. <https://www.axios.com/2022/06/28/biden-ev-charging-investments>
22. <https://www.epa.gov/greenvehicles/electric-vehicle-myths#Myth6>
23. <https://www.iihs.org/news/detail/with-more-electric-vehicles-comes-more-proof-of-safety>
24. <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions>
25. <https://blog.ucsusa.org/dave-reichmuth/are-electric-vehicles-really-better-for-the-climate-yes-heres-why>; <https://www.wsj.com/graphics/are-electric-cars-really-better-for-the-environment/>
26. <https://iopscience.iop.org/article/10.1088/1748-9326/ac5142>
27. https://energyinnovation.org/wp-content/uploads/2021/04/Energy-Innovation_2035-2.0-Accelerating-Clean-Transportation-Policy-Report.pdf

For more information, visit: [zeta2030.org/EVmyths](https://www.zeta2030.org/EVmyths)

CLEAN ENERGY BOOM

THE 142,016 (AND COUNTING) NEW CLEAN ENERGY JOBS
ACROSS THE UNITED STATES
UPDATED: MARCH 31, 2023

Since the landmark Inflation Reduction Act (IRA) became law in August 2022, companies are racing forward with massive investments to build our clean energy future. New manufacturing in wind, solar, batteries, and electric vehicles — along with storage projects across the country — mean new, good-paying jobs for hard-working Americans. In the months since the landmark climate and clean energy investments became law, clean energy companies have announced or moved forward with projects accounting for **more than 142,000 new clean energy jobs** for electricians, mechanics, construction workers, technicians, support staff, and many others.

As the largest U.S. investment in clean energy and climate in history, this national clean energy plan will continue to reshape and recharge our economy for many decades to come. The Made in America clean energy boom is just getting started.

This report analyzes public announcements from the private sector since the passage of the Inflation Reduction Act to demonstrate the breadth and scale of the growing clean energy economy being built all across the country.

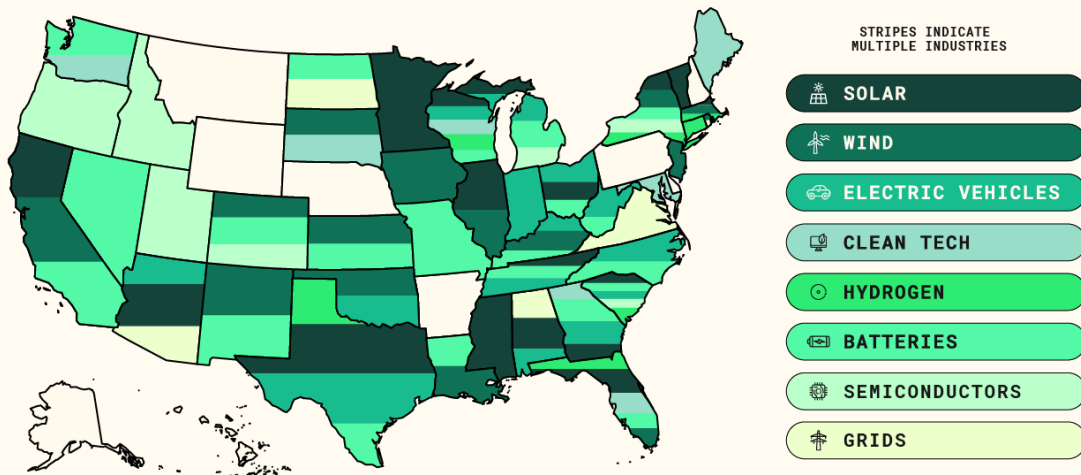
MORE THAN 142,016 NEW JOBS ACROSS THE COUNTRY

Clean energy projects creating **142,016 new jobs** in **41 states** were announced or advanced between August 16, 2022 and March 31, 2023. As of March 31, 2023, there are **191 new clean energy projects** in small towns and bigger cities nationwide totaling **\$242.81 billion in new investments**.

Plans include 65 new battery manufacturing sites in places like Tucson, Arizona; Rochester, New York; and Florence County, South Carolina. So far, companies have announced plans for 40 new or expanded electric vehicle manufacturing facilities in Savannah, Georgia; Montgomery,

Alabama; Auburn Hills, Michigan — and more. A further 34 plans were announced to expand wind and solar manufacturing in cities including Pensacola, Florida; Hutchinson, Kansas; and Georgetown, Texas. The majority of the projects are in 10 states — Arizona, California, Georgia, Michigan, New York, North Carolina, Ohio, South Carolina, Tennessee, and Texas.

NEW CLEAN ENERGY JOBS SINCE THE PASSAGE OF THE INFLATION REDUCTION ACT



SOURCED FROM NEWS ANNOUNCEMENTS AS OF 03.31.23

Driven in part by the certainty created by the clean energy plan and its incentives to build the clean energy future here at home, American companies restored almost [350,000 manufacturing jobs](#) in 2022 — a 25 percent increase from 2021. [A recent analysis](#) by the BlueGreen Alliance and the Political Economy Research Institute at the University of Massachusetts Amherst projects that the Inflation Reduction Act will create over 9 million clean energy and climate-related jobs over the next decade.

STATE SNAPSHOTS: THE CLEAN ENERGY ECONOMIC BOOM

States around the country have benefited from the provisions of the national clean energy plan. Even [climate skeptics have touted the benefits of the law](#) for their communities because they now understand that this clean energy plan means big investments in their communities and new jobs. Already, the new law has significantly benefited local economies and will provide family-sustaining wages in ZIP codes from coast to coast. The local economic benefits

will continue to spread across the country. Just in the first quarter of 2023, clean energy projects were announced or advanced in six new states: Connecticut, Florida, Maine, Mississippi, Utah, and Vermont.

10 STATES WITH MAJORITY OF PROJECTS	
STATE	# OF PROJECTS
ARIZONA	12 PROJECTS
CALIFORNIA	8 PROJECTS
GEORGIA	14 PROJECTS
MICHIGAN	14 PROJECTS
NEW YORK	11 PROJECTS
NORTH CAROLINA	7 PROJECTS
OHIO	9 PROJECTS
SOUTH CAROLINA	14 PROJECTS
TENNESSEE	9 PROJECTS
TEXAS	12 PROJECTS

ARIZONA

- LGES announced it would invest \$5.6 billion in an Arizona gigafactory to meet growing demand for U.S.-made EV batteries that qualify for [Inflation Reduction Act tax credits](#), a fourfold increase from previous plans. KORE Power CEO Lindsay Gorrill [applauded the passage of the Inflation Reduction Act](#) and said it provides an “[incredible lift](#)” to his company’s project in Buckeye, where it is developing a gigafactory [in hopes of claiming the law’s tax credits](#).

\$8.31 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



12,720

JOBS IN ARIZONA
SINCE PASSAGE OF THE IRA

CALIFORNIA

- Newly launched company Statevolt has plans to construct a [\\$4 billion and 54 GWh lithium-ion manufacturing plant in Southern California](#), to further the production of EV batteries in the state.

\$5.45 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



3,300

JOBS IN CALIFORNIA
SINCE PASSAGE OF THE IRA

COLORADO

- CS Wind announced plans to [expand the largest wind turbine factory in the world](#), located in Pueblo, Colorado. The CS Wind expansion will add two new buildings and triple the workforce, rivaling the state's steel plant.

\$1.07 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



1,467

JOBS IN COLORADO
SINCE PASSAGE OF THE IRA

GEORGIA

- [Freyr Battery](#) invested in a new Gigafactory in Coweta County, [QCells](#) is building a new [\\$2.5 billion solar panel factory](#) and planning to hire [400 new employees](#) to meet demand driven by the [Inflation Reduction Act](#), and [Hyundai Motor Group](#) and [SK On](#) jointly invested [\\$4 to \\$5 billion](#) to build

electric battery plants outside of Atlanta that will supply Hyundai and Kia EVs built in the U.S.

\$13.34 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



12,888

JOBS IN GEORGIA
SINCE PASSAGE OF THE IRA

MICHIGAN

- [Our Next Energy](#), a Michigan-based company, invested \$1.6 billion in their first battery manufacturing campus in Wayne County, EV battery maker [Gotion Inc. laid plans for a \\$2.4 billion factory](#) in Big Rapids, and [Magna invested \\$526 million](#) across several expansion projects to further Michigan's status as the "home of the auto industry and the future of mobility in Michigan," according to Governor Whitmer.

\$20.23 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



13,702

JOBS IN MICHIGAN
SINCE PASSAGE OF THE IRA



167,000

CLEAN ENERGY JOBS [PROJECTED](#)
IN THE NEXT 10 YEARS

MINNESOTA

- Cummins is driving the clean hydrogen economy forward in Minnesota, with the announcement of its [first U.S. electrolyzer production facility](#) in Fridley, Minnesota.
- Regulators approved Xcel Energy's plans to [build Minnesota's largest solar power plant](#), replacing electricity lost from closing coal-fired power plants across the state. The company also recently [announced the addition of battery storage](#) at the site, which will enable them to increase the grid's renewable capacity.

\$575 M

INVESTMENTS IN
CLEAN ENERGY PROJECTS



914

JOBS IN MINNESOTA
SINCE PASSAGE OF THE IRA

NEVADA

- Tesla is resuming construction on its \$3.5 billion expansion gigafactory in Nevada, set to produce 105 GWh of battery cell production and over 150 GWh of battery packs annually. The Department of Energy also funded several projects to help Nevada achieve its goal of becoming the “Silicon Valley of lithium.”

\$4.54 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



10,800

JOBS IN NEVADA
SINCE PASSAGE OF THE IRA



40,000

CLEAN ENERGY JOBS **PROJECTED**
IN THE NEXT 10 YEARS

NEW YORK

- Furthering New York’s vision to become the nation’s offshore wind manufacturing hub, GE proposed two new offshore wind energy manufacturing facilities in the state and Zinc8 Energy Solutions announced a \$68 million investment plan to relocate its battery manufacturing facility and U.S. headquarters to the mid-Hudson region. New York’s EV battery workforce is also growing with GM announcing a \$68 million investment to upgrade its Rochester, NY plant for EV battery components.

\$101.52 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



13,355

JOBS IN NEW YORK
SINCE PASSAGE OF THE IRA

NORTH CAROLINA

- Several new projects benefiting EV production are coming to North Carolina, including [Toyota's \\$2.5 billion investment](#) in their EV battery facility and [Wolfspeed's commitment to building](#) the world's largest silicon carbide materials facility in Chatham County, producing a material used for components in electric vehicles and solar equipment. Kempower [credited the Inflation Reduction Act](#) for the company's decision to build a \$41 million EV charging station manufacturing facility in Durham.

\$9.59 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



3,640

JOBS IN NORTH CAROLINA
SINCE PASSAGE OF THE IRA

OHIO

- [Honda and LG Energy Solutions are partnering on a \\$4.4 billion investment](#) to develop a battery plant project in Fayette County, the largest direct private investment in Ohio's history. Ohio is also becoming a hub for solar manufacturing, as First Solar made a [\\$680 million investment](#) to expand their solar plant in Wood County and Invenergy made a [\\$600 million investment](#) for a new solar plant that will create 850 new jobs.

\$7.76 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



5,200

JOBS IN OHIO
SINCE PASSAGE OF THE IRA

SOUTH CAROLINA

- BMW announced a [\\$1.7 billion investment](#) in South Carolina in their shift to EV manufacturing, and Bosch announced production of electric motors in Charleston [to the tune of \\$260 million](#).

- ABB E-mobility will expand its EV charger facility to [create up to 10,000 chargers](#) a year for transit buses, Envision AESC is [investing \\$810 million](#) in a new battery gigafactory in Florence County in partnership with BMW, and Redwood Materials is [investing \\$3.5 billion](#) to build a battery materials campus in Berkeley County.

\$10.92 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



11,060

JOBS IN SOUTH CAROLINA
SINCE PASSAGE OF THE IRA

TENNESSEE

- Tennessee has several projects set to bring jobs to the state: Piedmont Lithium announced plans to invest [\\$600 million in a new lithium hydroxide plant](#), Daejin Advanced Materials announced a [\\$10.2 million investment](#) in a new EV battery plant, NOVONIX Anode Materials shared a new battery plant project expected to [cost upwards of \\$1 billion](#), and LG Chem plans to invest [\\$3.2 billion in a battery cathode plant](#).

\$5.49 B

INVESTMENTS IN
CLEAN ENERGY PROJECTS



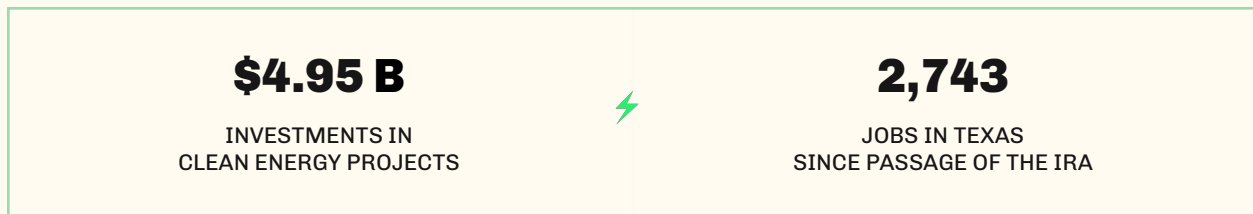
3,700

JOBS IN TENNESSEE
SINCE PASSAGE OF THE IRA

TEXAS

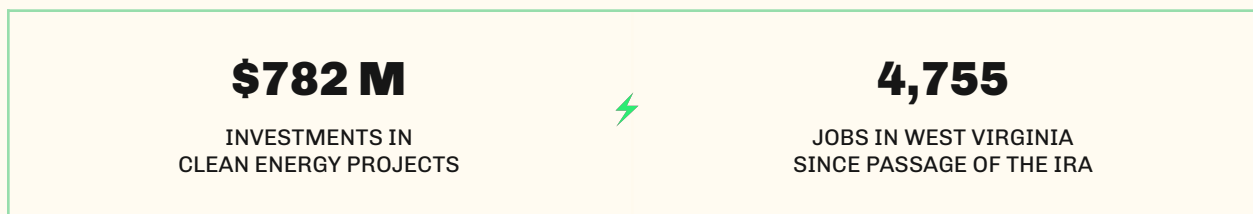
- Since the passage of the law, Texas has seen record investments: [SK Signet announced plans](#) for an EV fast charger manufacturing facility, [Tesla plans to invest \\$770 million](#) toward expanding its Austin EV factory, and Air Products and AES jointly announced a [\\$4 billion investment](#) for the companies' first mega-scale green hydrogen production facility.
- OCI and Mission Solar announced a [\\$40 million investment](#) to expand domestic solar module production facilities, and SEG Solar announced a new residential solar

project that will [bring 500 jobs to the state](#).



WEST VIRGINIA

→ [SPARKZ](#), [Form Energy](#), and [Our Next Energy](#) each announced plans to build battery plants. [Form Energy](#) will invest \$760 million in a longer lasting iron-air battery project, and [Our Next Energy](#) will invest \$22 million for a utility-scale battery factory.



ACROSS THE COUNTRY, NEW INVESTMENTS MADE IN ONGOING CLEAN ENERGY PROJECTS CONTINUE TO SPUR NEW JOBS.

BY THE NUMBERS		
STATE	INVESTMENT	JOBS
ALABAMA	\$1.33 BILLION	1,480 JOBS
ARIZONA	\$8.31 BILLION	12,720 JOBS
CALIFORNIA	\$5.45 BILLION	3,300JOBS
COLORADO	\$1.07 BILLION	1,467JOBS
CONNECTICUT	\$25.1 MILLION	45 JOBS
FLORIDA	\$451 MILLION	1,500 JOBS
GEORGIA	\$13.34 BILLION	12,888 JOBS
IDAHO	\$15 BILLION	2,000JOBS

ILLINOIS	\$895 MILLION	485 JOBS
INDIANA	\$2.22 BILLION	717 JOBS
IOWA	-	700 JOBS
KANSAS	\$4 BILLION	20,600 JOBS
KENTUCKY	\$3.26 BILLION	1,503 JOBS
LOUISIANA	\$861.4 MILLION	230 JOBS
MAINE	\$6 MILLION	200 JOBS
MARYLAND	\$70 MILLION	460 JOBS
MASSACHUSETTS	\$200 MILLION	250 JOBS
MICHIGAN	\$20.23 BILLION	13,702 JOBS
MINNESOTA	\$575 MILLION	914 JOBS
MISSISSIPPI	\$115 MILLION	300 JOBS
MISSOURI	\$400 MILLION	150 JOBS
NEVADA	\$4.54 BILLION	10,800 JOBS
NEW JERSEY	\$1.07 BILLION	200 JOBS
NEW MEXICO	\$404 MILLION	250 JOBS
NEW YORK	\$101.522 BILLION	13,355 JOBS
NORTH CAROLINA	\$9.59 BILLION	3,640 JOBS
NORTH DAKOTA	\$871 MILLION	150 JOBS
OHIO	\$7.76 BILLION	5,200 JOBS
OKLAHOMA	\$1.45 MILLION	2,015 JOBS
OREGON	\$1 BILLION	280 JOBS
RHODE ISLAND	\$729 MILLION	1,850 JOBS
SOUTH CAROLINA	\$10.92 BILLION	11,060 JOBS
SOUTH DAKOTA	\$1 BILLION	1,280 JOBS
TENNESSEE	\$5.49 BILLION	3,700 JOBS
TEXAS	\$4.95 BILLION	2,743 JOBS
UTAH	\$11 BILLION	800 JOBS
VERMONT	-	12 JOBS
VIRGINIA	\$37 MILLION	165 JOBS
WASHINGTON	\$1.72 BILLION	800 JOBS
WEST VIRGINIA	\$782 MILLION	4,755 JOBS
WISCONSIN	-	200 JOBS
STATE NOT SPECIFIED	\$107 MILLION	3,150 JOBS

TOTAL OF 142,016 JOBS

METHODOLOGY

This report analyzes public announcements from the private sector since the passage of the Inflation Reduction Act to demonstrate the breadth and scale of the clean energy economic boom happening all across the country. It tracks public announcements from the private sector between August 16, 2022 to March 31, 2023.

THE CLEAN ENERGY BOOM

IN HOUSE REPUBLICAN DISTRICTS

MORE THAN HALF OF NEW CLEAN ENERGY PROJECTS, JOBS AND INVESTMENTS ARE LOCATED IN DISTRICTS REPRESENTED BY HOUSE REPUBLICANS

Since the landmark Inflation Reduction Act (IRA) became law in August 2022, the private sector has been racing forward with massive investments to build our clean energy future. New manufacturing in wind, solar, batteries, and electric vehicles — along with storage projects across the country — mean new, good-paying jobs for hard-working Americans. In the months since the landmark climate and clean energy investments became law, clean energy companies have announced or moved forward with projects accounting for more than 142,000 new clean energy jobs for electricians, mechanics, construction workers, technicians, support staff, and many others.

At the same time as this massive clean energy boom is creating jobs in communities across the country, MAGA extremists in Congress have chosen this moment to try to repeal the IRA, killing clean energy jobs and reversing our nation's clean energy progress. All of this is made more confusing by the fact that **more than half of clean energy projects** that have been announced or moved forward since the passage of the IRA are located in districts represented by House Republicans. **In short, Republican MAGA extremists in Congress are ready to kill new, good paying jobs coming to their own districts to play politics and prioritize their oil and gas allies.**

This report analyzes the more than **191 clean energy projects** that have moved forward since the passage of the IRA and finds:

- More than half of all clean energy projects that have moved forward since the passage of the IRA are in districts represented by House Republicans: 107 clean energy projects in total located in 72 congressional districts across the country.
- Projects in these districts will create 77,261 jobs and generate more than \$198 billion in investments.
- The districts with the most clean energy projects include NV-2 (Rep. Mark Amodei), KY-1 (Rep. James Comer), TN-7 (Rep. Mark Green), GA-12 (Rep. Rick Allen), IN-5 (Rep. Victoria Spartz), SC-2 (Rep. Joe Wilson), WA-4 (Rep. Dan Newhouse).

- The districts with the highest number of clean energy jobs include NV-2 (Rep. Mark Amodei), NY-22 (Rep. Brandon Williams), GA-11 (Rep. Barry Loudermilk), WV-2 (Rep. Alexander Mooney), AZ-5 (Rep. Andy Biggs), MI-5 (Rep. Tim Walberg), and MI-2 (Rep. John Moolenaar).
- The districts with the largest dollar investment in clean energy include NY-22 (Rep. Brandon Williams), ID-2 (Rep. Michael Simpson), UT-3 (Rep. John Curtis), GA-11 (Rep. Barry Loudermilk) and AZ-5 (Rep. Andy Biggs).

107 CLEAN ENERGY PROJECTS IN 72 CONGRESSIONAL DISTRICTS REPRESENTED BY HOUSE REPUBLICANS ACROSS THE COUNTRY

According to a Climate Power analysis, more than half of the 191 clean energy projects with \$242.81 billion in new investments are in districts represented by House Republicans. In total of the 72 Republican members of Congress with new clean energy projects, 62 of them voted against the IRA on August 16, 2023. The 10 who didn't take the vote are freshman so they were not in Congress last year at the time of the vote. However, at least 7 of these members who were not in Congress at the time of the vote have said they oppose the bill.

The district with a House Republican representative with the highest number of new clean energy jobs is NV-2, the district represented by Rep. Mark Amodei, with 9,750. The second highest number of clean energy jobs is in NY-22 represented by Rep. Brandon Williams with 9,000 jobs.

Districts with the highest number of jobs:

- **Most:** 9,750 in NV-2 (Rep. Mark Amodei)
- **Second:** 9,000 in NY-22 (Rep. Brandon Williams)
- **Third:** 6,000 in GA-11 (Rep. Barry Loudermilk)
- **Over 2,000:** 3,750 in WV-2 (Rep. Alexander Mooney), 2,800 in AZ-5 (Rep. Andy Biggs), 2,500 in MI-5 (Rep. Tim Walberg), 2,350 in MI-2 (Rep. John Moolenaar), 2,205 in SC-5 (Rep. Ralph Norman), 2,200 in OH-15 (Rep. Mike Carey), 2,000 in ID-2 (Rep. Michael Simpson), 2,000 in OK-5 (Rep. Stephanie Bice)
- **Over 1,000:** 1,801 in TN-7 (Rep. Mark Green), 1,686 in GA-12 (Rep. Rick Allen), 1,515 in OK-2 (Rep. Josh Brecheen), 1,500 in SC-1 (Rep. Nancy Mace), 1,490 in TX-13 (Rep. Ronny Jackson), 1,280 in SD-At Large (Rep. Dusty Johnson), 1,170 in SC-7 (Rep. Russell Fry), 1,165 in AZ-9 (Rep. Paul Gosar), 1,150 in OH-12 (Rep. Troy Balderson), 1,142 in GA-1 (Rep. Earl Carter), 1,120 in TN-3 (Rep. Charles Fleischmann), 1,103 in KY-1 (Rep. James Comer), 1,005 in WV-1 (Rep. Carol Miller)

The district with a House Republican representative with the largest investments in clean energy projects is NY-22 represented by Rep. Brandon Williams with a \$100 billion investment.

Districts with the largest investments:

- **Largest:** \$100 billion in NY-22 (Rep. Brandon Williams)
- **Over \$10 billion:** \$15 billion in ID-2 (Rep. Michael Simpson) and \$11 billion in UT-3 (Rep. John Curtis)
- **Over \$5 billion:** \$7.5 billion in GA-11 (Rep. Barry Loudermilk), \$5.6 billion in AZ-5 (Rep. Andy Biggs)
- **Over \$2 billion:** \$4.42 billion in NV-2 (Rep. Mark Amodei), \$4.4 billion in OH-15 (Rep. Mike Carey), \$4.09 billion in TX-13 (Rep. Ronny Jackson), \$3.8 billion in NC-9 (Rep. Richard Hudson), \$3.58 billion in TN-7 (Rep. Mark Green), \$3.5 billion in SC-1 (Rep. Nancy Mace), \$3.5 billion in MI-5 (Rep. Tim Walberg), \$2.6 billion in GA-3 (Rep. A. Ferguson), \$2.4 billion in MI-2 (Rep. John Moolenaar)
- **Over \$1 billion:** \$1.74 billion in SC-5 (Rep. Ralph Norman), \$1.7 billion in KY-2 (Rep. Brett Guthrie), \$1.7 billion in SC-4 (Rep. William Timmons), \$1.62 billion in TN-3 (Rep. Charles Fleischmann), \$1.56 in KY-1 (Rep. James Comer), \$1.5 billion in IN-8 (Rep. Larry Bucshon), \$1.45 billion in OK-2 (Rep. Josh Brecheen), \$1.07 billion in NJ-4 (Rep. Christopher Smith), \$1 billion in SD-At Large (Rep. Dusty Johnson), \$1 billion in AL-4 (Rep. Robert Aderhot)

DISTRICT SNAPSHOTS: OUR NATION'S CLEAN ENERGY BOOM IS BRINGING JOBS AND INVESTMENTS TO DISTRICTS REPRESENTED BY HOUSE REPUBLICANS

Thanks to the Biden administration's clean energy plan, billions of dollars are flooding into districts represented by House Republicans across the country. These investments are popular. According to a [recent poll](#) from Navigator Research, the IRA is supported by 89% of Democrats, 62% of Independents, and 44% of Republicans.

Despite the popularity of these investments, Republicans in Congress voted against the IRA and now, are threatening to repeal the job-creating investments, directly impacting the local economies in their districts and their constituent's wallets and jobs.

- **Arizona's 6th Congressional District:** Rep. Juan Ciscomani represents Arizona's 6th Congressional district where 2 new clean energy projects are creating 245 jobs. As a freshman,

Rep. Ciscomani did not vote for the IRA in August 2022 but he has stated he [opposed](#) the IRA, and incorrectly [claimed](#) it would raise taxes without helping inflation.

- **Georgia's 14th Congressional District:** In January 2023, Qcells [announced](#) it would expand its operations in this Georgia district, adding 510 new jobs to capitalize on IRA incentives. Despite voting against the IRA and continuing to deny climate change, Rep. Marjorie Taylor Greene, who represents this district, told [POLITICO](#) that “we’re excited to have jobs” in response to the announcement.
- **Michigan's 9th Congressional District:** In October 2022, Magna announced a [\\$426 million expansion](#) of its electric vehicle structures manufacturing facility in Rep. Lisa McClain's district, which will create 920 new clean energy jobs. Rep. McClain voted against the IRA and [claimed](#) the bill was deceptive because it would do “nothing to reduce inflation”.
- **Nevada's 2nd Congressional District:** Represented by Rep. Mark Amodei, this district leads the nation in the highest number of clean energy jobs since the passage of the IRA. In total, the district has attracted 4 new clean energy projects generating 9,750 new jobs and more than \$4.4 billion in investments. Rep. Amodei voted against the IRA, [arguing](#) that the legislation prioritizes climate initiatives over traditional energy sources at a time of historic inflation, and that, “the sad truth is that our country is amid a recession, and this bill will only deepen our country's economic troubles.”
- **New York's 19th District:** Republican Rep. Marcus Molinaro represents this district. As a freshman, Rep. Molinaro didn't have the opportunity to vote on the IRA, but he [called](#) the legislation a “bad idea” that “does nothing to lower inflation.” According to a [release](#) from Sen. Schumer, IRA tax credits were a large driver behind Zinc8's decision to build in New York, and more specifically in Moninaro's district. The manufacturing hub is expected to create 500 new jobs.
- **New York's 22nd District:** This district, represented by Rep. Brandon Williams, leads the nation in clean energy investment since the passage of the IRA. Micron has invested \$100 billion in the district creating 9,000 direct clean energy jobs with the construction of their New York Semiconductor Megafab Facility. The project, [announced](#) in October 2022, will produce microchips for EVs and other technologies and will create another 40,000 indirect community jobs. Although Rep. Williams didn't have the opportunity to vote on the IRA, according to an October 2022 [article](#) in Politico, Rep. Williams “opposed the [IRA], which he called a giveaway to special interests that would drive continued inflation.”
- **South Carolina's 1st Congressional District:** Redwood Materials [announced](#) it would invest \$3.5 billion to build a battery recycling campus that will create 1,500 clean energy jobs in this district, represented by Rep. Nancy Mace. [Redwood Materials cited](#) the “benefits of the recent

[IRA]” in announcing the new campus. Rep. Mace voted against the IRA, and claimed the legislation’s “massive spending” wouldn’t lower inflation.

BY THE NUMBERS				
DISTRICT	MEMBER	NUMBER OF PROJECTS	TOTAL JOBS	TOTAL INVESTMENT
AL-3	REP. MIKE ROGERS	1	180	\$8,000,000
AL-4	REP. ROBERT ADERHOT	1	700	\$1,000,000,000
AL-5	REP. DALE STRONG	1	200	\$125,000,000
AZ-5	REP. ANDY BIGGS	1	2,800	\$5,600,000,000
AZ-6	REP. JUAN CISCOMANI	2	245	\$0
AZ-9	REP. PAUL GOSAR	3	1,165	\$0
CO-3	REP. LAUREN BOEBERT	2	700	\$0
CO-5	REP. DOUG LAMBORN	1	400	\$880,000,000
FL-1	REP. MATT GAETZ	1	0	\$20,000,000
FL-2	REP. NEAL DUNN	1	300	\$0
GA-1	REP. EARL CARTER	2	1,142	\$367,000,000
GA-3	REP. DREW FERGUSON	1	723	\$2,600,000,000
GA-6	REP. RICHARD MCCORMICK	1	200	\$19,000,000
GA-9	REP. ANDREW CLYDE	1	400	\$0
GA-10	REP. MIKE COLLINS	1	0	\$0
GA-11	REP. BARRY LOUDERMILK	2	6,000	\$7,500,000,000
GA-12	REP. RICK ALLEN	3	1,686	\$872,000,000
GA-14	REP. MARJORIE TAYLOR GREENE	1	510	\$171,000,000
IA-1	REP. MARIANNETTE MILLER-MEEKS	1	700	\$0
ID-2	REP. MICHAEL SIMPSON	1	2,000	\$15,000,000,000
IL-15	REP. MARY MILLER	1	0	\$360,000,000
IN-5	REP. VICTORIA SPARTZ	3	75	\$721,000,000
IN-8	REP. LARRY BUCSHON	1	642	\$1,500,000,000
KS-1	REP. TRACEY MANN	1	100	\$0
KY-1	REP. JAMES COMER	4	1,103	\$1,569,564,400
KY-2	REP. BRETT GUTHRIE	1	400	\$1,700,000,000
LA-5	REP. JULIA LETLOW	1	120	\$444,816,850
MI-2	REP. JOHN MOOLENAAR	1	2,350	\$2,400,000,000
MI-5	REP. TIM WALBERG	1	2,500	\$3,500,000,000
MI-9	REP. LISA MCCLAIN	1	920	\$426,000,000
MI-10	REP. JOHN HAMES	1	155	\$96,170,000
MN-6	REP. TOM EMMER	1	914	\$575,000,000
MS-4	REP. MIKE EZELL	1	300	\$115,000,000

NC-9	REP. RICHARD HUDSON	1	350	\$3,800,000,000
NC-10	REP. PATRICK MCHENRY	2	230	\$375,525,233
ND-AL	REP. KELLY ARMSTRONG	2	150	\$871,872,271
NJ-2	REP. JEFFERSON VAN DREW	1	200	\$0
NJ-4	REP. CHRISTOPHER SMITH	1	0	\$1,070,000,000
NV-2	REP. MARK AMODEI	4	9,750	\$4,429,322,049
NY-19	REP. MARCUS MOLINARO	1	500	\$68,000,000
NY-21	REP. ELISE STEFANIK	1	90	\$500,000,000
NY-22	REP. BRANDON WILLIAMS	1	9,000	\$100,000,000,000
NY-23	REP. NICHOLAS LANGWORTHY	1	250	\$75,000,000
OH-4	REP. JIM JORDAN	1	300	\$700,000,000
OH-12	REP. TROY BALDERSON	2	1,150	\$782,514,939
OH-14	REP. DAVID JOYCE	1	0	\$170,000,000
OH-15	REP. MIKE CAREY	1	2,200	\$4,400,000,000
OK-2	REP. JOSH BRECHEEN	2	1,515	\$1,450,000,000
OK-5	REP. STEPHANIE BICE	1	2,000	\$0
SC-1	REP. NANCY MACE	1	1,500	\$3,500,000,000
SC-2	REP. JOE WILSON	3	410	\$397,000,000
SC-3	REP. JEFF DUNCAN	1	350	\$200,000,000
SC-4	REP. WILLIAM TIMMONS	2	300	\$1,700,000,000
SC-5	REP. RALPH NORMAN	2	2,205	\$1,743,000,000
SC-7	REP. RUSSELL FRY	1	1,170	\$810,000,000
SD-AL	REP. DUSTY JOHNSON	2	1,200	\$1,000,000,000
TN-3	REP. CHARLES FLEISCHMANN	2	1,120	\$1,627,260,704
TN-5	REP. ANDREW OGLES	2	650	\$275,000,000
TN-7	REP. MARK GREEN	4	1,801	\$3,584,740,145
TN-8	REP. DAVID KUSTOFF	1	150	\$107,000,000
TX-4	REP. PAT FALLON	1	200	\$0
TX-8	REP. MORGAN LUTTRELL	1	500	\$0
TX-13	REP. RONNY JACKSON	2	1,490	\$4,090,000,000
TX-26	REP. MICHAEL BURGESS	1	100	\$0
UT-3	REP. JOHN CURTIS	1	800	\$11,000,000,000
VA-5	REP. BOB GOOD	1	165	\$37,000,000
WA-4	REP. DAN NEWHOUSE	3	800	\$722,936,774
WI-1	REP. BRYAN STEIL	1	0	\$0
WI-3	REP. DERRICK VAN ORDEN	1	0	\$345,000,000
WI-8	REP. MIKE GALLAGHER	1	200	\$0
WV-1	REP. CAROL MILLER	2	1,005	\$22,000,000
WV-2	REP. ALEXANDER MOONEY	2	3,750	\$760,000,000

TOTALS	72 DISTRICTS	107	77,261	\$198,182,723,365
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METHODOLOGY

This report analyzes public announcements from the private sector since the passage of the IRA. It builds on Climate Power’s [full analysis](#) of all 191 public announcements from the private sector between August 16, 2022 to March 31, 2023.



Big winners from Biden's climate law: Republicans who voted against it

GOP lawmakers voted en masse against Biden's signature bill. But roughly two-thirds of green-energy projects announced since it became law are going to Republican-held congressional districts, a POLITICO analysis found.



The GOP is likely to find itself in an uncomfortable position as funding from the Inflation Reduction Act plays a growing role in Republicans home states and districts. | Godofredo A. Vásquez/AP Photo

By [Kelsey Tamborrino](#) and [Josh Siegel](#)

01/23/2023 01:14 PM EST

Updated: 01/23/2023 03:32 PM EST

They didn't vote for it, they don't like it and they're working to undermine it — but Republicans are reaping the benefits of Democrats' climate law.

In the five months since the Inflation Reduction Act became law, companies have announced tens of billions of dollars in renewable energy, battery and electric vehicle projects that will benefit from incentives in President Joe Biden's signature law, aimed at expanding domestic manufacturing in clean energy and reducing dependence on Chinese imports.

In fact, roughly two-thirds of the major projects are in districts whose Republican lawmakers opposed the Inflation Reduction Act, according to a POLITICO analysis of major green energy manufacturing announcements made since the bill's enactment.

The dynamic has prompted a tricky balancing act for the GOP: Tout the jobs and economic benefits coming to their states and districts, but not the bill that helped create them. The results are also potentially awkward for Democrats who expended political capital and more than a year of wrangling to enact the bill, only to see Republican lawmakers and governors sharing in the jobs and positive headlines it's creating — although Democrats say they also see longer-term benefits for the nation in building GOP support for alternatives to fossil fuels.

Republicans insist their positions on the bill and the jobs are not in conflict.

"Just because you vote against a bill doesn't mean the entire bill is a bad bill," said Rep. Garret Graves (R-La.), who was the top GOP member of Democrats' Select Climate Crisis Committee in the last Congress. "I go out there and advocate for our district to try and get transportation funds, to try and get energy funds. That's my job. I am not embarrassed about it. I don't think it's inconsistent with my vote."

To Democrats, the slate of new investments stand as proof that they were correct that the Inflation Reduction Act, H.R. 5376 (117), would expand the reach of clean power to rural and conservative areas — a promise that failed to sway a single Republican vote to support the bill.

"It's hard not to point out the hypocrisy for people who fought tooth and nail against the bill, those very incentives that are now creating opportunities in their [Republican] districts they are now leading," said Sen. Tina Smith (D-Minn.). "We just have to point out, thanks for your kind words, but this didn't just happen. It happened despite your best efforts."

Smith attended an October ribbon-cutting in her state for Canadian solar panel maker Heliene's [expansion of its manufacturing facility](#) — an effort that was started prior to the Inflation Reduction Act's passage and that has [drawn praise](#) from Rep. Pete Stauber (R-Minn.), whose district is home to the plant that will be one of the largest panel makers in the country.

Energy Secretary Jennifer Granholm welcomed the news that Republican districts were drawing the investments.

“Great, that is fantastic,” she told reporters at the Monday White House briefing. “We want to be able to see energy — clean energy — produced in every pocket of the country. Blue states, red states, really it helps to save people money, so it’s all about green.”

Democrats’ climate law includes billions of dollars to spur green energy technologies and cut greenhouse gas emissions, including a new tax credit for manufacturing the components crucial for solar, wind and electric vehicles, as well as additional incentives for using domestic content in projects.

Republicans, though, have moved to slash funding of the Internal Revenue Service, the central agency charged with implementing the climate law’s incentives, over concerns that Democrats have expanded its mandate. And Friday, former President [Donald Trump urged GOP lawmakers](#) to target “billions being spent on climate extremism” in their fight over the debt limit.

Supporters of the Inflation Reduction Act say its success is due in part to the way it provides long-term certainty for companies looking to place a footprint in the U.S.

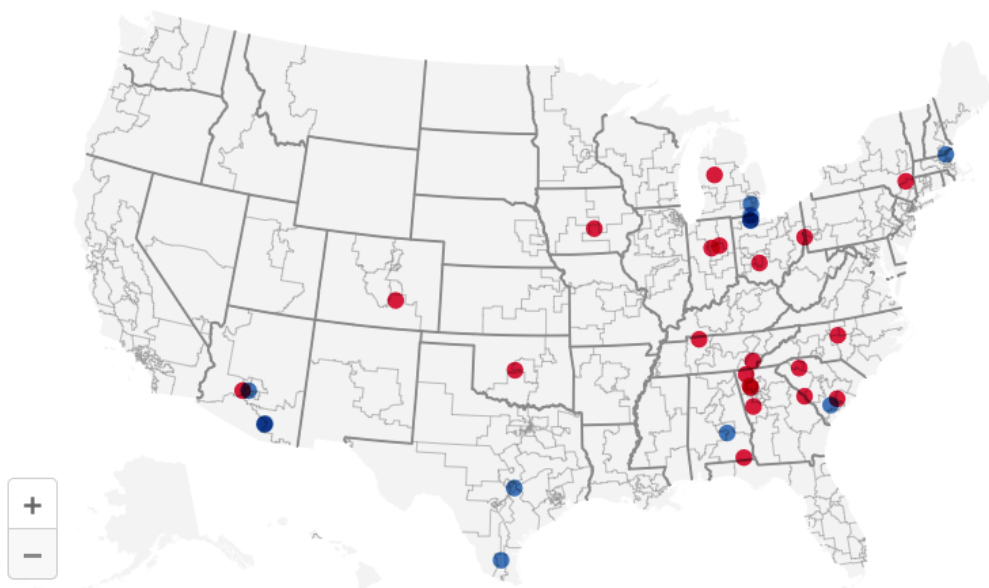
The bill is a “fundamental element” of the recent spate of manufacturing announcements, said Abigail Ross Hopper, the president and CEO of the Solar Energy Industries Association. “There certainly were a number of plans being evaluated and discussed [prior to the bill]. But I think the vast majority were contingent upon the passage of the IRA.”

Most clean energy projects landing in red districts

Wind, solar, battery and electric vehicle manufacturing projects announced since President Joe Biden signed the climate law on Aug. 16

Party of project location’s representative

■ Democrat ■ Republican



Company	House district	Representative	Location
American Battery Factory	● AZ-07	Raúl Grijalva	Tucson, Ariz.
BMW / Envision AESC	● SC-04	William Timmons	Woodruff, S.C.
Canoo	● OK-05	Stephanie Bice	Oklahoma City, Okla.
CS Wind	● CO-03	Lauren Boebert	Pueblo, Colo.
Factorial Energy	● MA-03	Lori Trahan	Methuen, Mass.
First Solar	● AL-04	Robert Aderholt	Lawrence County, Ala.
First Solar	● OH-09	Marcy Kaptur	Perrysburg, Ohio
Form Energy	● WV-02	Alex Mooney	Weirton, W.Va.
Freyr Battery	● GA-03	Drew Ferguson	Coweta County, Ga.
General Motors	● IN-05	Victoria Spartz	Marion, Ind.
General Motors	● OH-09	Marcy Kaptur	Toledo, Ohio
Gotion	● MI-02	John Moolenaar	Big Rapids, Mich.
Honda / LG Energy	● OH-15	Mike Carey	Fayette County, Ohio
Hyundai Mobis	● AL-07	Terri Sewell	Montgomery, Ala.
Hyundai / SK	● GA-11	Barry Loudermilk	Cartersville, Ga.
JA Solar	● AZ-07	Raúl Grijalva	Phoenix, Ariz.
Kontrolmatik Technologies	● SC-06	Jim Clyburn	Walterboro, S.C.
LG Chem	● TN-07	Mark Green	Clarksville, Tenn.
Meyer Burger	● AZ-09	Paul Gosar	Goodyear, Ariz.
Misson Solar	● TX-28	Henry Cuellar	San Antonio, Texas
Our Next Energy	● MI-06	Debbie Dingell	Van Buren Township, Mich.
Piedmont Lithium	● TN-03	Chuck Fleischmann	Etowah, Tenn.
Q Cells	● GA-11	Barry Loudermilk	Bartow County, Ga.
Q Cells	● GA-14	Marjorie Taylor-Greene	Dalton, Ga.

Redwood Materials	● SC-01	Nancy Mace	Ridgeville, S.C.
Sion Power Corp.	● AZ-07	Raúl Grijalva	Tucson, Ariz.
Solvay / Orbia	● GA-12	Rick Allen	Augusta, Ga.
Soulbrain MI	● IN-05	Victoria Spartz	Kokomo, Ind.
Tesla	● TX-35	Greg Casar	Austin, Texas
Toledo Solar	● OH-09	Marcy Kaptur	Perrysburg, Ohio
Toyota	● NC-09	Richard Hudson	Liberty, N.C.
TPI Composites	● IA-01	Mariannette Miller-Meeks	Newton, Iowa
Zinc8	● NY-19	Marc Molinaro	Ulster County, N.Y.

Note: This data does not include projects where the precise location was unavailable.

Source: American Clean Power Association, GovTrack.us, media reports and company announcements

Kelsey Tamborrino/POLITICO

In the three months after Biden signed the Inflation Reduction Act in August, companies announced more than \$40 billion of new clean energy investments, according to a December report from the American Clean Power Association, an industry trade group. POLITICO’s analysis of the law’s early results includes those projects as well as separate news reports and company announcements of manufacturing expansions and plans, and additional announcements on electric vehicle plants.

Out of 33 projects examined, 21 are expected to be located in Republican-held congressional districts, compared with 12 in Democratic districts. POLITICO’s analysis did not reflect every announcement made and does not include facilities where a specific congressional district could not be found.

Just this month, South Korean solar company Hanwha Q Cells announced it would invest \$2.5 billion in Georgia to expand its solar panel manufacturing plant and construct another facility in the state.

That expansion is occurring partially in the district of conservative firebrand Rep. Marjorie Taylor Greene — who has described climate change as “actually healthy for us” and has blasted Democrats’ bill. Greene, however, recently told POLITICO that she’s “excited to have jobs” in her district that will come from the Q Cells announcement, though she gave credit to Georgia’s GOP Gov. Brian Kemp, [who has courted clean energy and electric vehicle manufacturing investments](#) through state-level subsidies and tax incentives.

Federal and state incentives alike are playing a role in the companies' decisions, said J.C. Bradbury, an economics professor at Kennesaw State University in Georgia.

"They are coming to Georgia for one reason — we are paying them to come here with subsidies," Bradbury said in an interview, referring to the combination of federal and state tax credits. "These projects are being pitched as economic development projects 100 percent."

But while manufacturing proponents point to factors including geography, economic development plans and states' anti-union laws as factors drawing investment to deep-red districts, they also say the announcements are directly tied to the federal subsidies provided under Democrats' bill.

"It's not random," said Jason Walsh, executive director of the BlueGreen Alliance, which includes labor unions and environmental organizations. "It's because specific policies have been put in place and passed by the U.S. Congress to actually incentivize exactly the kind of activity that we're seeing."

And the investments are only expected to grow. Solar manufacturer and Bill Gates-backed CubicPV, for one, is planning a 10-gigawatt facility in the United States, but has not yet chosen a location, while Enel North America, a unit of an Italian energy company, is evaluating sites to build a new solar panel and cell manufacturing plant. Battery manufacturing facilities are also expected to come online in the years ahead across several states, including Michigan, Tennessee, Arizona and Georgia.

Companies aren't necessarily looking at which lawmaker represents the district when they invest, said Scott Paul, president of Alliance for American Manufacturing. They're looking instead at where the supply chains exist and where they can leverage the tax benefits and capital provided by lawmakers.

"Red state-blue state [is] not really a factor," Paul said, adding, "This isn't one of those things that looks like an electoral map at all."

Republicans express no regret about [opposing the IRA despite previously supporting individual pieces of the bill](#), such as tax incentives for carbon capture, nuclear and hydrogen projects. GOP members argued that the bill would pump too much money into the economy and worsen inflation, and they've criticized Democrats for using the partisan reconciliation process that allowed them to pass it with a simple majority in the Senate.

"The overall process, the overall bill, particularly the spending, really frustrates Republicans — not necessarily every specific in the bill," said Rep. John Curtis (R-Utah).

But the GOP is likely to find itself in an uncomfortable position as funding from the Inflation Reduction Act plays a growing role in Republicans home states and districts.

Former Virginia Democratic Rep. Tom Perriello, who lost his reelection bid in 2010 after voting for the Affordable Care Act, said those dynamics put Republicans in a tricky spot once voters see the jobs stemming from Democrats' agenda.

"Biden has driven his agenda right down Main Street with a big 'Made in America' banner on the back of an electric truck, and people's only choices are to get on board with the parade or seem to be against making things in America again," he said. "I think of those two choices, Republican hypocrisy makes a lot more sense than standing in the way of jobs and American competitiveness."

He called it "squirrely" for lawmakers to argue to voters that they like certain parts of the bill, but not others.

"That's just not how legislating works. That's not how things pass," he said.

House Republicans have promised robust oversight of the climate law, pledging to seek out wasteful spending in search of would-be scandals such as the failed Solyndra loan guarantee of the Obama administration — even if the overall program is a success.

"I don't think it complicates the oversight," a House GOP leadership aide told POLITICO, who asked for anonymity to speak candidly. "Oversight is an important function. There could be 20 great projects [supported by IRA], but if one is bad, it's our job to understand why."

Republicans also criticized the Biden administration's rush to embrace greener energy while the country still relies on China for technology components, and they've been critical of government support that has helped companies with manufacturing in China.

Virginia Gov. Glenn Youngkin, a Republican, said he [rejected Ford Motors' efforts to consider locating a battery plant](#) in his state over concerns about China and national security.

Democrats, though, hope the trend of clean energy boosting the economic prospects of red states helps shift the rhetoric of Republicans and enables more bipartisan cooperation on narrow interests benefiting the climate.

"Over time, I anticipate their [Republican] talking points will change as their neighbors become a part of the clean energy economy," said former House climate committee Chair Kathy Castor (D-Fla.).

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Wind turbines. Image courtesy of Zach Shahan, CleanTechnica.

CLEAN POWER

Want To Electrify Everything? Train More

Electricians — Quickly

The US Bureau of Labor Statistics projects growth of electrician jobs will increase by 9.1% from 2020 to 2030.



By [Carolyn Fortuna](#) Published March 7, 2023



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We have heard the call over the past few years to electrify everything. Doing so will rapidly decrease carbon emissions and help to stave off dangerous levels of global warming. The pace of installing EV chargers, solar panels, induction stoves, heat pumps, wind turbines, transmission lines, and everything else needed for the world to run on 100% clean power by 2050 is amazing to watch. It also requires the expertise of electricians. Unfortunately, there are not enough electricians to fulfill the enormous need. We need to train more electricians — a lot more electricians.

The electrical industry say the country is already facing an electrician shortage — and it could get worse as clean energy ramps up.

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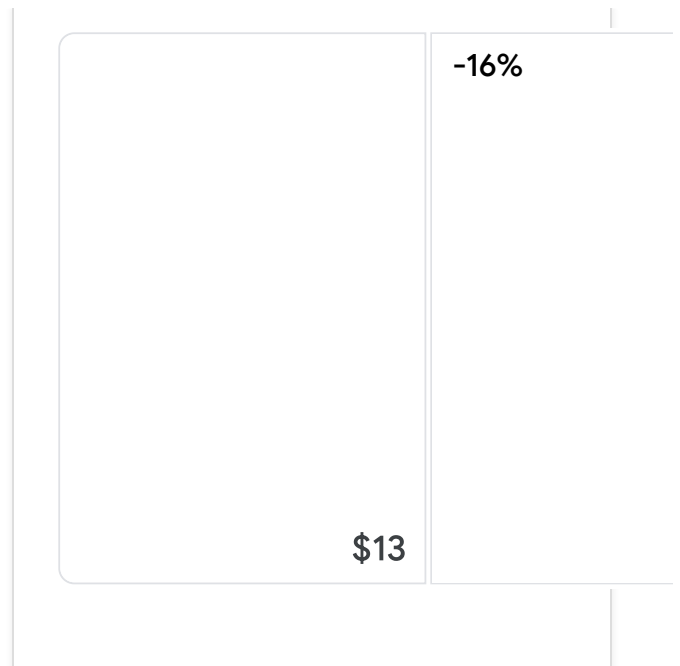




The Federal Push for Electrifying Everything

There is \$72 million devoted in the Bipartisan Infrastructure Bill for training the clean energy workforce. Then there is the Inflation Reduction Act (IRA), which is appropriating \$200 million for job training,

“Due to legislative achievements such as The Inflation Reduction Act, initiatives that increase investments in renewable energy are contributing to the growth of careers in the energy sector,” says Jason Miller, CEO of PromoLeaf, a Utah-based promotional products company, told *CleanTechnica* in an exclusive. “In fact, green jobs in renewable energy are the fastest-growing when it comes to careers in the green sector.”



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Miller reveals that some of the hot jobs for electricians within the next decade are Wind Turbine Technicians (set to grow by 68%) and Solar Photovoltaic Installers (expected to increase by 52%).

The median salary in a green job is \$76,530/year, Miller describes, which is 31% more than the national median salary for the US workforce (\$58,260). The information is part of PromoLeaf's [Green Jobs Report](#) analysis.

[Rewiring America](#) concurs, explaining that the Inflation Reduction Act (IRA) will deliver “huge savings” in the US:

- **Household benefits:** The average American household will receive \$10,600 in IRA benefits to fully electrify.
- **Household savings:** Households will save on average \$1,800 per year.

- **Number of households:** 120 million households across the country can benefit from these provisions.
- **Number of jobs created:** 1.4 million direct and 5 million total jobs can be created in the US.

New York, Boston, Seattle, and San Francisco are requiring that new buildings run only on electricity. Berkeley, California, pioneered the legislation in 2019.

What can the US and other countries do to train more electricians as the nation adapts to more renewable power generation? How will upgrades to transmission capacity be affected by a deficit of electricians? A robust workforce is needed to wire, connect, and install new electric lines.

However, moving away from fossil fuels is sometimes viewed as a dangerous decision since it might cost the country jobs in fossil fuel industries; coal mining is showcased as an example. Yet the coal mining industry today employs around 37,000 people — less than 6% of the number of people employed as electricians. Existential fear on the part of the fossil fuel industry has resulted in scare tactics that make legacy workers

question whether they'll find a place in the new all electric workplace.

Change is in the air, though.

Rewiring America [explains](#) that shifting the economy [away from fossil fuels](#) will require no fewer than 1 billion new electrical appliances, cars, and other items in US households alone. For example, people are becoming keenly aware that, on average, replacing a gas powered car with an EV will slash carbon pollution by about two-thirds when calculated over the car's life span — even when accounting for the grid's current makeup and the emissions associated with the vehicle and battery production.

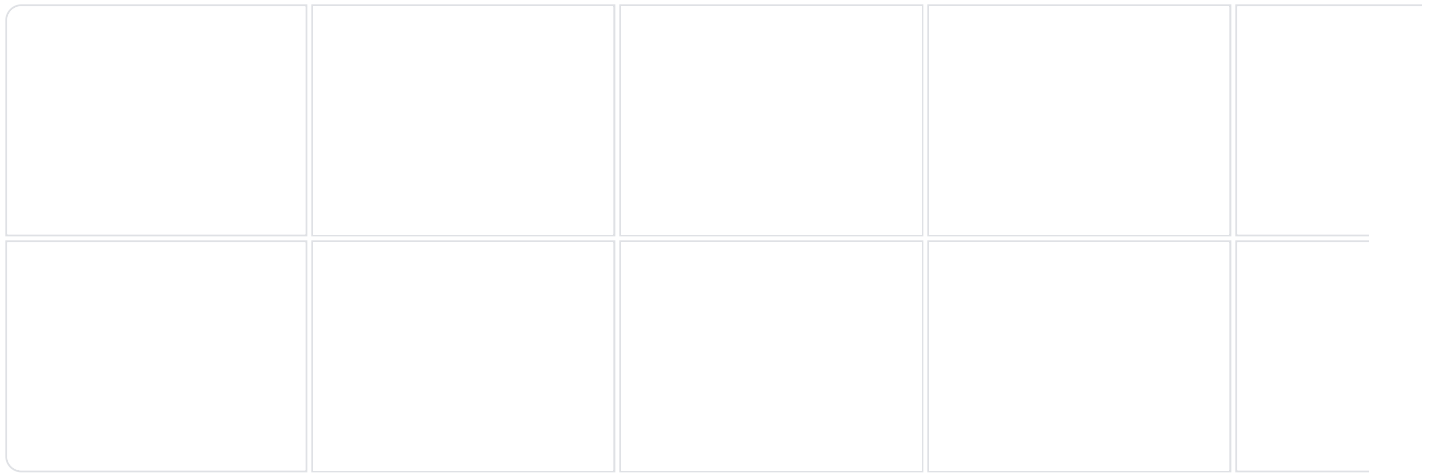
Where are the electricians to install those EV chargers?

What Will It Take to Train More Electricians?

Green sector jobs continue to be [on the rise](#). With that broad designation, the US Bureau of Labor Statistics projects growth of electrician jobs will increase by [9.1%](#) from 2020 to 2030. New

approaches to incentivize workers to join the electrical field will help.

Apprentices wanted: Workers wanting to become electricians have to do an apprenticeship first, either through a union or a company. The Inflation Reduction Act, the landmark climate law passed by Congress in August, includes a requirement that companies that receiving tax incentives for wind and solar energy also employ a certain portion of apprentices: 10% of labor hours in 2022 and 15% by 2024. The Biden-Harris administration has highlighted registered apprenticeship to address some of the nation's pressing workforce challenges, according to outgoing [US Secretary of Labor Marty Walsh](#). The federal initiative "will further support private-public partnerships that help youth across the country access a college education, good-paying jobs, and strong pathways to the middle class."



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Bring unions into the conversation: It will be essential to [collaborate](#) with union labor so accepted standards and pay will be incorporated into large projects and retrofits. Union training programs can also help increase the number of electricians in the field, but they typically operate and blossom when there is guaranteed demand.

Replace the negative connotation to the Trades: More than [75%](#) of high school and college students in 2021 wanted to work in technology, therefore more likely to [attend college](#) than pursue a [skilled labor job](#). The desire for jobs with flexible hours and potential for remote work often steers them away from trade jobs. Some groups are working to expose more young people to the options of joining a trade like the electrical field. Those efforts include offering support through the first few months of employment.

Municipal help: Municipal governments can take on the role of converting their electrified buildings into training centers for workforce development. They can install charging networks directly wired to municipal power lines instead of requiring residents to go solo with new infrastructure.

Invest in underrepresented people and places: Additional investment in retraining and reskilling is imperative in order to train more electricians. So, too, is focusing on under-invested communities and demographics, veterans, and the persons who had once been incarcerated.

Final Thoughts

At least \$25.7 billion in new US clean energy factories are in the works, thanks in part to the subsidies in Biden-Harris administration's landmark climate law, the Inflation Reduction Act. Beneficiaries of federal legislation will help the US to wean off fossil fuel power, but it will take more electricians to make the vision a reality.

Ever thought about being an electrician? You should, because the job is always in demand, you have potential for massive

career growth, and working as an electrician is both a challenging and rewarding career. The time has never been better to join the field!

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WRITTEN BY

Carolyn Fortuna



Carolyn Fortuna (they, them), Ph.D., is a writer, researcher, and educator with a lifelong dedication to ecojustice. Carolyn has won awards from the Anti-Defamation League, The International Literacy Association, and The Leavy Foundation. Carolyn is a small-time investor in Tesla. Please follow Carolyn on [Twitter](#) and [Facebook](#).

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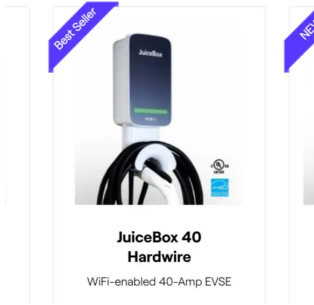
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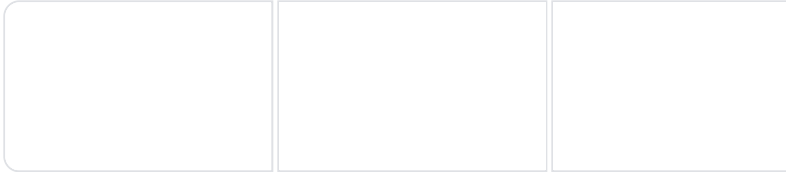
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Mobilizing for a zero carbon America:

Jobs, jobs, jobs, and more jobs

A Jobs and Employment Study Report

Saul Griffith*, Sam Calisch†
with help from
Alex Laskey‡and Rewiring America§

For release : July 29, 2020

Summary

Total decarbonization of America’s energy system is often portrayed as being inconsistent with economic growth, particularly with respect to job opportunities for those currently working in more traditional energy industries. This report, based on an extensive industrial and engineering analysis of what such a decarbonization would entail, demonstrates that aggressive decarbonization would create, rather than destroy, many millions of well-paying American jobs. These jobs will be highly distributed geographically and difficult to off-shore. The opportunity to create even more jobs by becoming an exporter of clean energy technologies would increase the number of jobs.

Where most studies look at decarbonization in specific individual sectors such as transportation, the electricity grid, or buildings — and mostly only on the supply side — we build a model of the interactions of all sectors, both supply and demand, in a rapid and total decarbonization. The maximum speed at which the transition can occur is dictated by the speed at which productive capacity in critical industries is built out. We call this the “mobilization period,” akin to the “arsenal of democracy” mobilization in service of winning WWII. Under our model, this period is followed by a prolonged stretch of deployment at close to 100% adoption rates. After this deployment period, the economy settles into a “new normal state” that provides steady growth, replacement, and maintenance of a 100% clean energy system.

This maximum feasible rate of decarbonization substantially decarbonizes the power, transportation, building, and industrial sectors in the U.S. by 2035. This is commensurate

*Otherlab, MacArthur Fellow, MIT PhD, saul@otherlab.com

†Elmworks, MIT PhD, sam@elm.works

‡Rewiring America, Founder O-Power

§A 501.3c organization dedicated to rapid decarbonization by mobilization of mass electrification.

the DOE “billion ton” report [3]⁴. Hydrogen or other synthetic fuels (which are generated from electricity) are deployed for a few high-temperature applications. The scenario does not rely on any deployment of carbon capture and storage (CCS)⁵, and all primary energy sources are net zero. We do not assume significant efficiency or behavioral changes, but rely on technology transformation instead. High electrification of the economy can be shown to reduce our primary energy needs by more than 50% (from ~ 98 Quads down to ~ 42) using only the inherent efficiency of electric vehicles over internal combustion engines (ICEs), of heat pumps over combustion heat sources, and on a smaller scale of LEDs over incandescents. From this model we build a “machines-up” account of the decarbonization transition, counting each specific piece of equipment required to make the transition. This accounting includes solar panels, heat pumps, and electric dryers, and also electrifying equipment that can be used for energy storage such as hot water heaters and electric vehicles. The jobs analysis presented here is grounded in the physical machines and equipment built for the decarbonization transition. The new machinery and equipment are priced against the fossil alternative (e.g. \$30,000 electric vehicle (EV) vs. \$20,000 internal-combustion engine (ICE) vehicle) and the resulting difference is established as the cost incurred for the changeover. These costs are then used to calculate direct, indirect, and induced jobs, using standard economic methods based on data from IMPLAN. We compare this economic job creation estimation with existing estimates of energy jobs, engineering estimates of jobs created, and with historically analogous projects of this level of ambition to confirm the reality of the very large number of jobs that this model projects.

Analysis Summary

- The maximum feasible transition (MFT) involves two primary stages: (i) an aggressive WWII-style production ramp-up of 3–5 years, followed by (ii) an intensive deployment of decarbonized infrastructure⁶ and technology up to 2035. This includes supply-side generation technologies as well as demand-side technologies such as electric vehicles and building heat electrification.
- MFT also calls for close to 100% adoption of decarbonized technology when fossil machines reach retirement age. This is fairly simple to imagine: when someone’s car reaches retirement age, it is replaced with an electric vehicle. When a natural gas plant is retired, it is replaced with nuclear or renewables.
- An MFT approach would create as many as 25 million net new jobs at peak.
- Every American household would accrue savings of \$1,000–2,000 per year due to lower, more predictable energy prices.

⁴This is sufficient to run all aviation (≈ 2 Quads), non fossil mining and construction equipment (≈ 0.5 Quads), on-farm diesel (≈ 0.6 Quads) and a good portion of freight trucking (≈ 5.5 Quads)

⁵While “tech neutral” and politically seductive, the cost of CCS puts all fossil fuel sources at a severe cost disadvantage to wind and solar. Further, a CCS-heavy scenario assumes we have enough places to reliably sequester this carbon, which is impractical to say the least.

⁶We use a broad definition of infrastructure encompassing all machinery that generates, stores, or can shift electrical loads. This means including EV’s, home HVAC, and the like as 21st century infrastructure.

- The government spending portion for such a transition is \$300bN per year for 10 years for an approximate total of \$3 trillion.
- This decarbonization pathway is commensurate with a global climate target of limiting warming to between 1.5° C/2.7° F and 2° C/3.6° F – assuming there is no significant deployment of carbon dioxide removal, that other major manufacturing nations (China, Germany, Japan, and South Korea) all follow suit in short order (within a decade), and that some nations are unlikely or unable to decarbonize quickly and are slower to respond.
- The job creation and the costs of such an ambitious nation-building project turn out to be similar in size and scope and new employment opportunities to the mobilization of U.S. industry for WWII.

Decarbonization

This study articulates a decarbonization strategy from the ground up. It provides an engineering account of what machines and infrastructure need to be replaced economy-wide, and on what timeline. This analysis is based on an assessment of the physical industrial setting – that is, rather than set emissions-reductions targets for various points in time and work backwards from there, as most models do, our approach looks at what machines and equipment currently exist and models the resulting “bottom-up” decarbonization pathway that follows. This approach demonstrates and illustrates the sort of transition that is possible and beneficial for first-mover economies that act rapidly and concertedly.

Figure 3 illustrates the decarbonization pathways for various climate targets. The pathways highlight the question of so-called committed emissions, the carbon emissions that will be emitted by machinery and infrastructure already in place through their useful lifetime [4]. What we can see from these simplified charts is that close to 100% adoption rates of decarbonized technology at end-of-life replacement are required for pathways commensurate with limiting warming to under 2° C/3.6° F. End of life-time replacement can be illustrated in a straightforward manner. When a car reaches retirement age, it is replaced with an electric one. When a coal plant is retired ⁷, it is replaced with nuclear or renewables.

In order to create a very specific estimate of jobs created by an energy system transition, we use detailed energy data to model out a pathway to completely decarbonize all energy related emissions in the U.S. The energy sector addresses ~85% of emissions, with the remaining emissions coming from agriculture [5] and some esoteric industrial emissions. As per Figure 4 we move sector by sector through the economy and use existing technologies that can eliminate carbon emissions in that sector. We then estimate the future energy flow required to service that sector. No efficiency measures are assumed other than the inherent efficiencies of the substitution technologies. As an example it is assumed that nearly all vehicles will be electrified and that because the electricity is coming from renewables and

⁷Early retirement of our heaviest emitters is the only proven way we can improve our climate outlook, but today has proven very politically unpopular, at least partly because of the perception of lost jobs.

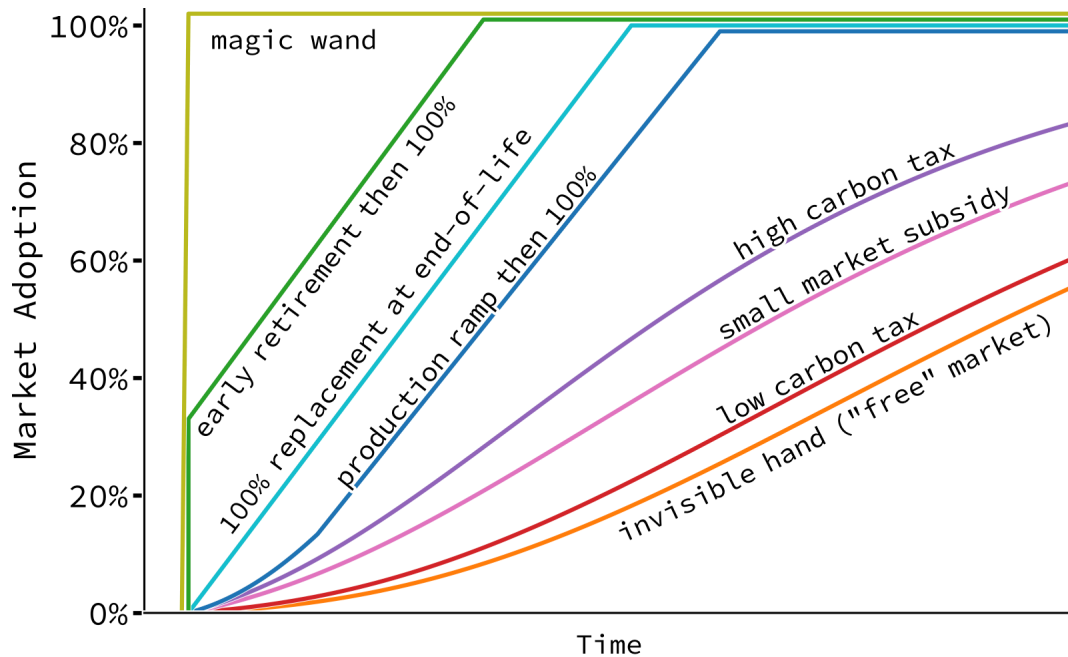


Figure 2: Market adoption is the measure of penetration of a new technology. With 100% adoption of clean energy technologies we could be living carbon-free. The rate at which we get to 100% adoption will determine what global climate change we will get. We can contextualize different mechanisms for motivating increased market adoption where the "invisible hand", or a purely free market, is the slowest, and a magic wand that overnight changes all of our infrastructure to clean is the fastest.

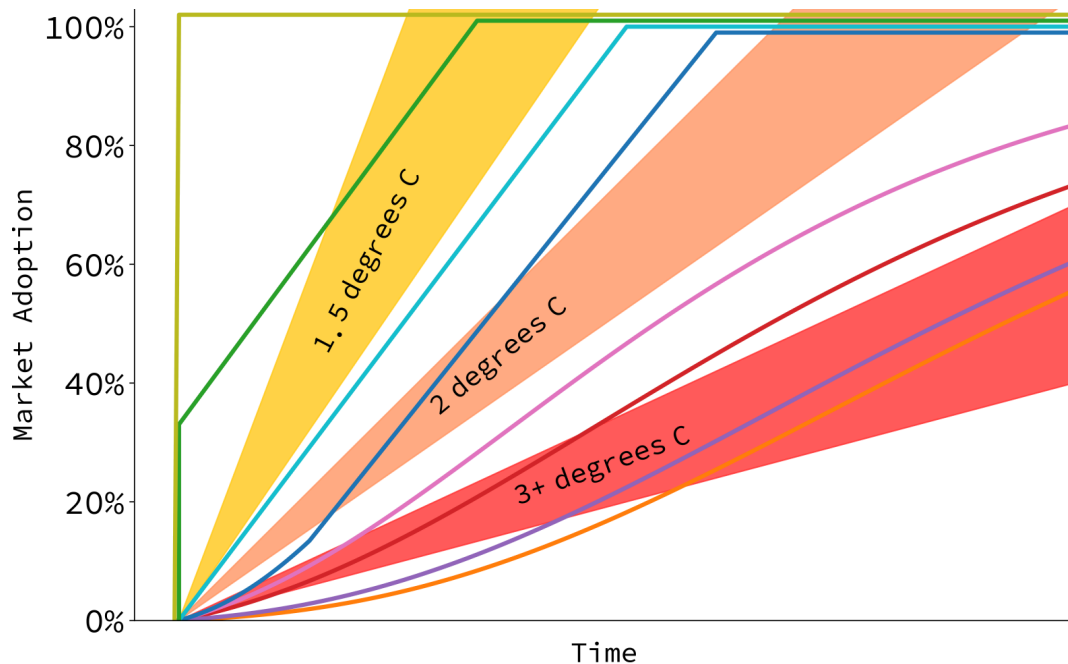


Figure 3: Time is up for slow rate-of-adoption free market solutions. The question becomes: Which set of incentives or regulations are best to speed up action? The only pathways that stay under $2^{\circ}\text{C}/3.6^{\circ}\text{F}$ involve close to 100% adoption rates of decarbonized technologies at the end of life of all fossil fuel burning machines.

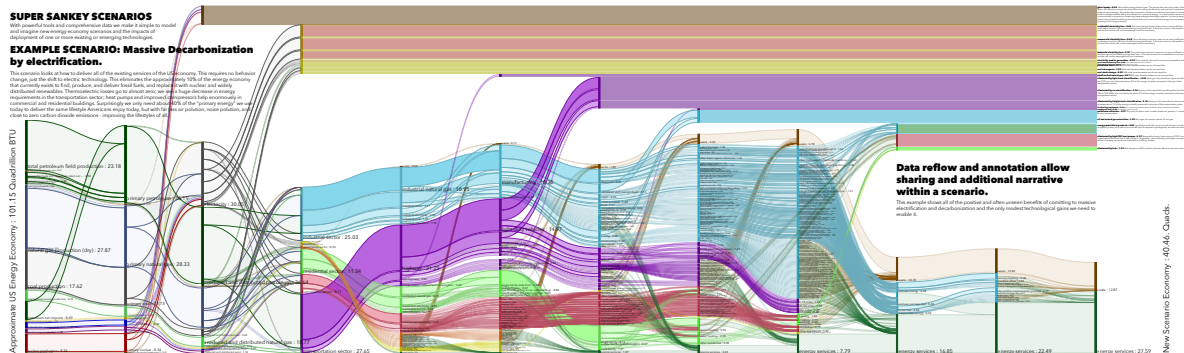


Figure 4: A Sankey flow diagram of all US energy flows (based on 2018 data) where we have modeled out the primary energy reductions of electrification. This model gives a clear viewpoint on a total decarbonization strategy that does not rely on the invention of any new technology.

nuclear, it will eliminate 16 quads of primary energy⁸; similarly, by producing all of our electricity with non-combustion sources, we eliminate 25 quads of thermo-electric losses. Electrification of buildings and the elimination of energy used to find, mine, and refine fossil fuels offer similarly large savings. It is found that the US only requires 40-50%⁹ of its current energy needs by this high electrification pathway. It is assumed that biofuels or (something like) renewably generated hydrogen will be used in some of the small but difficult to decarbonize sectors such as long-distance aviation and steelmaking. This much electrification would mean the U.S. would need between 1,500 and 2,000 GW of net delivered electricity – between 3 and 4 times the current average of around 450GW. We assume the majority of this electricity will be produced with solar and wind, along with a doubling of the current nuclear electricity fleet from 100GW to 200GW. The decarbonization pathway we model is highly electrified.

This specific model of complete energy system decarbonization allows for a ground-up jobs estimate — based on knowing which machines and infrastructure need to be replaced with emission-free electrical machines and infrastructure¹⁰. The model does not assume much by way of efficiency apart from the inherent efficiencies of the electrical machinery replacing the fossil equipment. Similarly we don't assume any behavioral change, rather relying on technology transformation. This translates as replacing gas-powered pick-up trucks with electric pick-up trucks, and natural gas burning furnaces with electric heat pumps.

In short the model assumes:

- A highly electrified economy that reduces total primary energy need down to around 45-50 Quads (from 100).

⁸One *Quad* is one quadrillion (10^{15}) British Thermal Units (BTUs). For reference, today we use about 100 Quads to run the U.S.

⁹This is consistent with the highly electrified pathway outlined in [6].

¹⁰This method of thinking was first proposed by Koomey in chapter 3 of “Cold Cash, Cool Climate” and described as “Working forward towards a goal” — meaning choose your target, then figure out how to get there. This is in contrast with much analysis which begins with some version of the question “what is politically possible?”.

- The great majority of that energy with renewable and nuclear electricity (1,500GW of new delivered electrical power).
- Near total electrification of transportation.
- Biofuels or electrically generated fuels will be used for aviation and some mining, freight, and construction equipment.
- The model accounts for capital expenditure to decarbonize industrial processes.
- Very high penetration of distributed (rooftop and community) resources is assumed, accounting for around 25% of energy supply and a high degree of the storage capacity.

The end result of the modeling effort is this:

- Decarbonizing America on this time frame produces as many as 25 million new jobs (at peak), tapering off to about 5 million sustained jobs, roughly double the number of jobs supported directly, and indirectly, by the current energy industry.
- The total government share of the expense is likely only \$250-350 billion per year, with the total public and private spending over 20 years at about 20-25 trillion dollars.
- With appropriate regulatory policies and implementation, energy costs will be lower and the average household will save \$1,000–2,000 per year.
- The majority of jobs that are created will be highly distributed throughout the economy. High-paying jobs are located in every zip code.

Estimating jobs

The effect of any decarbonization approach on the quantity and quality of available jobs is necessarily critical, both in terms of the ability to adopt and implement any such approach and its effect on people’s lives. This consideration is only heightened in a post– COVID–19 world.

The MFT decarbonization model outlined here is well-suited to meet this challenge. Unemployment currently stands at a level higher than any point in time since the Great Depression [9]. For context and comparison we can look at the long-term history of unemployment in the US in [Figure 5](#). At the height of the Great Depression more than 20% of Americans were unemployed. The public works and jobs programs undertaken under the administration of President Franklin Roosevelt made progress in addressing employment starting in 1935, but it wasn’t until the war that the job situation changed significantly. Once the mobilization of American industry to manufacture war materials for WWII kicked in, the unemployment rate plummeted from north of 15% to 2–3% in a year or so.

It is useful to note that the WWII buildup included not only a decrease in unemployment of around 15% (of a 53 million person 1939 labor force), or around ~8 million jobs, but also an increase in the labor force of 18% which represented another ~9.5 million jobs. This was

U.S. Historical Unemployment Rate

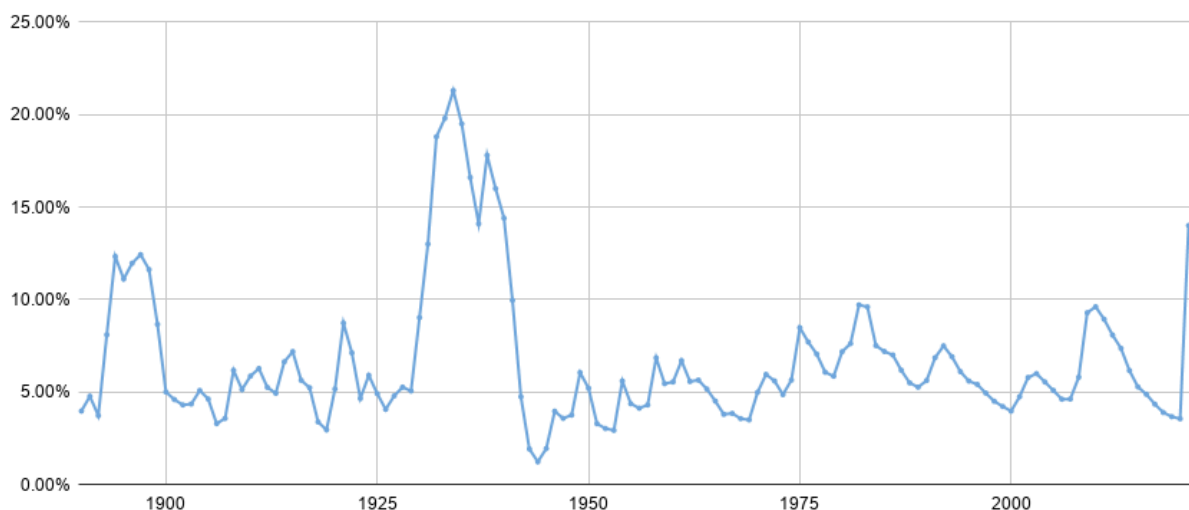


Figure 5: *The estimated U.S. Unemployment rate from 1890 to 2020. 1890–1930 data from [7], 1930–1940 data from [8], 1940–2020 data from Bureau of Labor Statistics [9].*

an addition of 17.5 million new jobs, which is useful to put the estimates in this paper of 25 million peak new jobs in a labor pool of 150 million people in perspective.

This real-world experience illustrates the employment potential of a rapid transition to a clean energy economy. Probably the only viable project of the scale necessary to reignite economic growth and return to full employment is decarbonizing America’s energy system. This is equally true in many other countries in the world.

Below is a more detailed analysis of the job-creation opportunities associated with a rapid transition to a clean energy economy.

Job Creation Drivers in Transition to a Clean Economy.

Increasing employment under the transition to a zero-carbon is driven by the requirement for more labor in manufacturing, installation, and maintenance of renewables than their counterpart fossil fuel technologies. It takes more people to install and keep a wind farm running than it does to drill a well and keep it pumping for the same amount of energy over time. Renewables get their fuels for free, whereas fossil fuels cost money. It takes more labor and maintenance to access those free renewable fuels. This is a very desirable tradeoff in an economy with massive unemployment.

The double-edged sword explicit in any jobs analysis is that if there are more jobs, then the energy will be more expensive. But higher up—front jobs for building the infrastructure for free “fuels” in the future means many more jobs in the short term, more sustained jobs in the longer term, and lower energy costs almost immediately (if the appropriate financing and regulatory policies are enacted).

Calculating accurate estimates of job creation due to investments in decarbonization is

Nameplate power / job (kw/job) vs. year (SEIA)

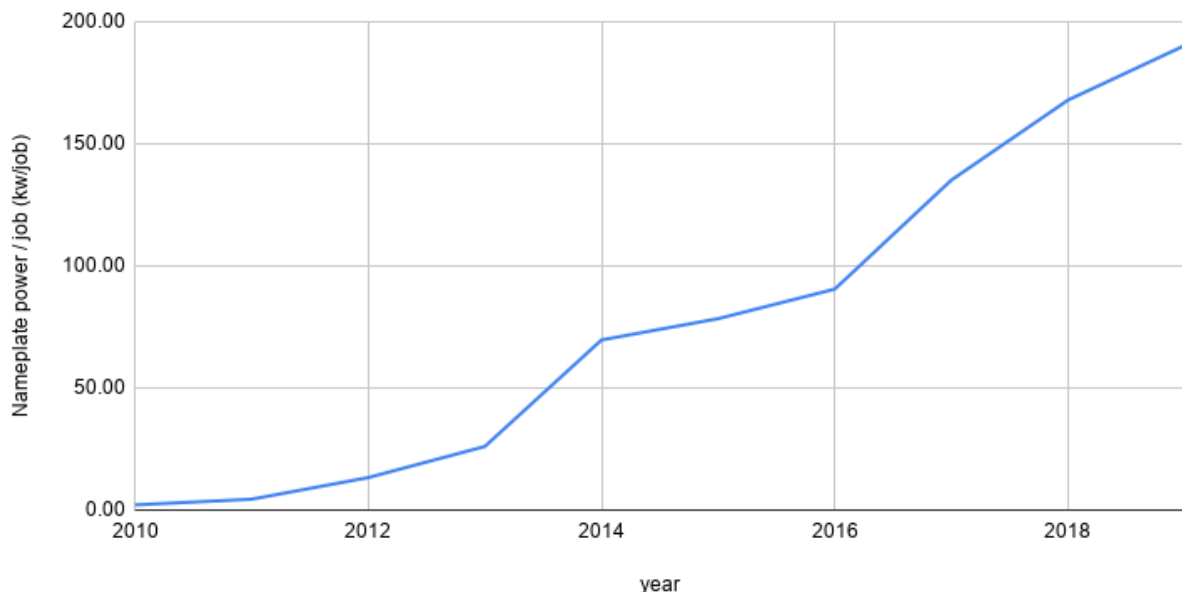


Figure 6: Estimates of employment per kW of nameplate installed capacity from 2010-2019, from [10] and [11].

challenging. As an example, consider the commonly-used method of assuming a fixed ratio of jobs per unit of electricity for a given technology. This allows us to estimate the number of jobs created by an investment by extrapolating this fixed ratio. In Figure 6, we plot the number of jobs per kilowatt of installed solar photovoltaics, using data from the Solar Energy Industries Association (SEIA) [10] and from the U.S. Energy Information Administration’s Electric Power Monthly report [11]. We can see that over the period from 2010 to 2019 this ratio did not, in fact, stay constant. Instead, it increased by nearly two orders of magnitude due to the learning rate of the industry.

As we can see, blindly applying fixed ratios of job creation is problematic, but extrapolating from the trend is slightly more reasonable. If we naively assumed 100% of our power would be supplied by solar, and that it is installed over 20 years, this implies more than a million direct jobs for this component alone.

Wind energy creates fewer jobs per kilowatt than solar, and a similar analysis using American Wind Energy Association (AWEA) data would suggest around 0.5 million sustainable-forever jobs if we supplied all of the U.S. energy needs with wind generated electricity.

Multipliers from jobs meta-analysis applied to this decarbonization strategy

Given the unreliability of the trade industry estimates and the unrealistic nature of supplying all energy from a single source, the next best method uses meta-studies of job estimates to synthesize across multiple sources. For instance, from the data of [1] we can estimate

New Capacity (GW)	Type	Multiplier	Jobs
500	Industrial solar	0.23	1,007,400
150	Rooftop / Solar	0.87	1,143,180
100	Nuclear	0.14	122,640
700	Wind	0.17	1,042,440
50	Hydro	0.27	118,260
100	Bio-fuels	0.21	183,960
1600			3,617,880

Table 1: *Estimate of supply side jobs using data of [1].*

jobs/GWh on the energy supply side in our decarbonization scenario, shown in [Table 1](#).

That’s more than 3.6 million *direct* jobs on the supply side, before counting the demand-side portions of the scenario.

Even before adding more details, we might then ask, how does this compare to the existing energy industry? What we’ll find out next is that only counting the supply side, this is already double the number of direct jobs in the existing energy industries.

Current Energy Industry Jobs

The Bureau of Labor Statistics (BLS) maintains excellent publicly available data on jobs in their “Current Employment Statistics” monthly reports[12]. We arrange it in [Figure 7](#) as a treemap that breaks down the big categories into increasingly small ones — answering the question that Richard Scarry [13] sought to answer in his famous children’s book *What do people do all day?*¹¹.

What immediately stands out as we write this are the very large categories of jobs susceptible to a pandemic like the novel coronavirus: 17 million jobs in leisure and hospitality, 16 million people in retail trade, 12 million people in public and private education. We can see why a pandemic requiring social isolation causes so much unemployment so quickly. Energy jobs are easily identified by pulling the jobs related to energy out of this same dataset. We show them in [Table 2](#).

What is immediately apparent is just how few people are directly employed by the energy industry — about 2.7 million if you count gas station convenience stores jobs, and about 1.8 million if you leave those out. The largest number of people employed in fossil fuels from this perspective are the nearly one million working in gas stations. However, convenience stores also sell snacks and sundries, so we don’t completely categorize them as energy industry employees; convenience stores sell 80% of the gas in this country.

Next, we can identify the jobs in coal mining — around 50,000 — and compare that to, for example , the 450,000 people who work in hair styling and barber shops, the 370,000 who work in golf clubs, or the more than 10,000,000 who work in restaurants.

The BLS data is based on North American Industry Coding System (NAICS) codes.

¹¹For the data-inclined, the Bureau of Labor Statistics does keep marvelous numbers on time use beyond employment in their [Time Use Survey](#) dataset.

Job category	Number of Jobs	Fossil?
Fossil fuel electric power generation	83,200	Y
Nuclear and other electric power generation	61,300	
Electric bulk power transmission and control	25,300	
Electric power distribution	212,700	
Natural gas distribution	110,600	Y
Pipeline transportation	51,100	Y
Gasoline stations with convenience stores	851,800	
Other gasoline stations	101,400	Y
Oil and gas pipeline construction	152,400	Y
Power and communication system construction	216,500	
Petroleum	102,800	Y
Petroleum refineries	68,600	Y
Electric power and specialty transformers	28,400	
Electricity and signal testing instruments	370	
Turbine and power transmission equipment	99,200	
Mining and oil and gas field machinery	69,500	Y
Oil and gas extraction	155,800	Y
Support activities for oil and gas operations	247,800	Y
Bituminous coal and lignite surface mining	22,800	Y
Bituminous coal underground mining and anthracite mining	28,300	Y
Total	2,689,870	
Total without gas station convenience stores	1,838,070	
FOSSIL ONLY	1,194,300	

Table 2: *January 2020 US jobs related to the energy economy, from BLS[12]*

January 2020, BLS, Employment Data, U.S., 152,212,000 Jobs.

(1.2%) Energy
1,838,070

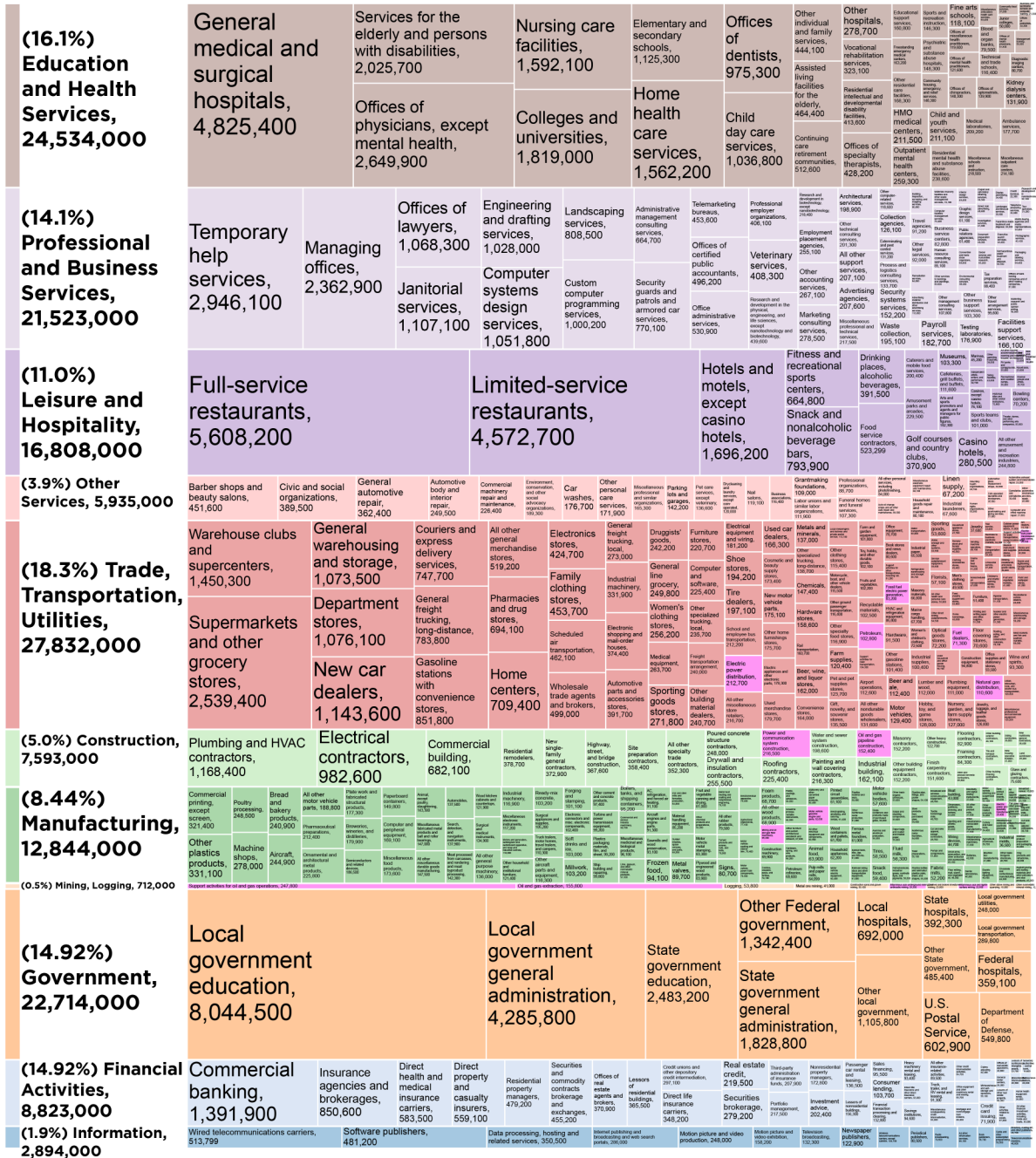


Figure 7: *All US jobs, Pre-COVID-19. Data from [12]. Get out your glasses!*

Job category	Current Jobs	Heuristic of future jobs
Fuels	1,149,000	~150,000
Electric power generation	897,000	~2,300,000
Transmission, distribution and storage	2,400,000	~6,000,000
Energy efficiency	2,380,000	~4,400,000
Motor vehicles	2,550,000	~2,000,000
Total	9,376,000	14,850,000

Table 3: *USEER estimate of total energy industry jobs 2016 [14]*

Many federal data sets are arranged by this coding system, including energy surveys such as the Manufacturing Energy Consumption Survey (MECS). It is important to note that many jobs don’t fit perfectly into these buckets, and categories of jobs change over time. Further confounding the data is that people might spend a small part of their day doing energy work, and the rest of their day doing construction; consider a small town electrical installer who sometimes does solar panels and energy efficiency retrofits like heat pump water heaters, but also does hot tub installations and wiring for non-energy related home renovations. Given these limitations, we can take a look at a deeper study of energy industry jobs.

USEER Estimates

Since 2015, The National Association of State Energy Officials (NASEO) and the Energy Futures Initiative (EFI) have produced the U.S. Energy and Employment Report (USEER)[14].

This report is compiled from a comprehensive survey of industries and individuals throughout the energy economy, and builds a comprehensive outlook on jobs from the resulting data. The USEER came about in 2016 after the DOE recommended reviewing how we count energy jobs in the 2015 first installment of the Quadrennial Energy Review (QER)¹² *“to reform existing data collection systems to provide consistent and complete definitions and quantification of energy jobs across all sectors of the economy.”*[15]

The USEER breaks down energy into five different energy sectors: the “traditional,” which include (1) fuels (1,149,000 jobs), (2) electric power generation (897,000), and (3) transmission, distribution and storage (2,400,000). The other two are (4) energy efficiency (2,380,000) and (5) motor vehicles (2,550,000). In 2020 the first 4 sectors employed 6.8 million Americans, or 4.6% of a workforce of 149 million. For reference, that is similar to the total number of people who work in finance and insurance (6.5 million). If we include those who work in motor vehicles under energy jobs, it is close to 9.4 million. The summary is presented in Table 3.

We can heuristically discuss each of these categories, and reason whether the number of jobs in those categories increases or decreases as we decarbonize.

The fuels category obviously decreases, but not to zero, as natural gas and to a lesser extent oil are used in substantial amounts in the plastics and fertilizer industries. A small amount of natural gas for seasonal peaker plants is also likely to stay on the grid for reliability

¹²The Quadrennial Energy Review is surprisingly readable, has great charts and images, and would be a great start for anyone wanting to develop an energy information hobby :) See [15] and [16].

reasons. Let's suggest this number might decrease by 80%, to around 150,000 (transitioning out around 1 million jobs).

Electric power generation is set to increase 3 to 4 times, which if applied as a multiplier on current electric power generation jobs gives an additional 1.8–2.7 million jobs. As a sanity check, we see this is in rough agreement with the solar energy industry example above.

Transmission, distribution, and storage also need to increase 3–4 times. That's another 4.8–7.2 million new jobs.

Energy efficiency is ill-defined currently, but we know that we need to do a huge number of end-use technology transformations for stove-tops, hot water heaters, furnaces, and the necessary home and commercial electrical upgrades (breaker boxes, etc) to make it possible. This is in addition to weatherization and existing efficiency jobs. It is hard to imagine that this category doesn't double or more given the pace of transformation required suggesting an increase of at least 2 million new jobs.

Finally, we consider motor vehicles – a fraught category. We know that electric vehicles should require less maintenance, because they have fewer components and fluids to replace. In contrast, they also weigh more, which typically correlates to more assembly labor. Most industry pundits believe there will be fewer jobs in an electrified automotive industry, but it is too early to tell just how many. Expanding factory automation is likely to be as significant a driver of job reduction in this sector as the change in technology from ICEs to EVs, whether or not we decarbonize. If we assume a reduction of 20% that's around 500,000 fewer jobs. Aggressively scaling U.S. production of EVs could allow the country to command more of the global vehicle export industry, more than offsetting hypothetical losses due to converting the vehicle fleet to electric.

Adding up the changes in this very gross estimate, we see around 1.5 million jobs transitioning out, replaced by as many as 10 million new jobs transitioning in.

We can see from these sector-specific, simplistic analyses that we can expect total employment in the energy industry to increase substantially, but just how substantially is beyond the scope and accuracy of these types of estimates. We provide them here as a framing for the more rigorous econometric analysis that we undertook which is a more traditional way of estimating job creation from macro-economic interventions.

A detailed econometric jobs forecast

Our analysis employs traditional economic models to estimate jobs and job creation, such as the Job and Economic Development Impact (JEDI) models employed by the National Renewable Energy Labs (NREL), to estimate job creation in the wind, solar, and other renewables industries[17].

Under this approach, job creation is estimated by understanding how much economic activity will occur (in millions of dollars), using estimates based on historical job creation in different industries per dollar. This econometric approach also takes a more expansive view of jobs, which includes (1) direct jobs (similar to those we counted earlier), which are jobs that are concretely and specifically in energy; (2) indirect or supply chain jobs, which are the jobs that support and service the direct jobs. A direct job might be installing natural gas pipelines, and an indirect job related to that is making the steel for the pipes, or the valves

and pumps for the pipeline. Induced jobs (3) are the jobs that are created in a community around the direct and indirect jobs. These are the people employed in the restaurants, schools, local retail stores, and other facilities that service the direct and indirect jobs. The woman installing wind farms gets a handsome pay check that she'll spend a good portion of in her local economy employing butchers and bakers and LED makers.

The application of the methodology then is pretty straightforward. (1) Estimate the amount of money it will take to build all of the things we need to decarbonize the economy. (2) Use the ratio of direct jobs per million dollars spent for that economic sector. This number is calculated by looking at the employment statistics by industry sector over time, and comparing it to the economic activity in the sector over time. A specialist company called Implan develops and maintains databases of this kind [18]. (3) Calculate indirect jobs and induced jobs as multipliers of this number.

By example, \$1,000,000 (2017 dollars) spent in construction creates 5.38 direct jobs, 3.87 indirect jobs, and 10.22 induced jobs. That is 19.77 jobs created per million dollars. This can tell you the *gross* number of new jobs. The *net* number of jobs must subtract out jobs that will be lost, or pre-existing jobs that overlap or will be absorbed by the new activity. We must find career transitions for the phased out coal mining and find jobs for those 50,000 miners, whereas we are not phasing out the 2,500,000 jobs in the auto industry, as they'll be redirected to electric vehicles and other net-zero carbon vehicle options. Careful and methodical accounting was undertaken to make sure we are not double-counting jobs and that we include the eliminated or transitioned jobs.

The first task is defining what we need to build, then we can address how much it will cost. This calculation is from an engineering approach, from the bottom up, and consequently this report offers one of the most detailed estimates of what it takes to decarbonize ever presented.

Remember that we will need somewhere between 1500 and 2000 GW of new electricity capacity on the supply side to decarbonize. That will need millions of miles of new and upgraded transmission and distribution to get to the end user. Finally on the demand side we'll need to electrify our 250 million vehicles, 130 million households, 6 million trucks, all of our manufacturing and industrial processes, and 5.5 million commercial buildings covering 90 billion square feet.

For the purposes of this analysis, and to help make sure we don't double-count anything, we'll divide the work into 8 large categories.

1. **Supply Build-Out:** The new-generation capacity for everything that will be electric and additional biofuel capacity for those things (like aviation) that won't. We base the build-out on costs of build-out in 2017, and with a goal of 1500 new GigaWatts (net) of zero-emission infrastructure to add to the existing 300GW.
2. **Transmission and Distribution Build-Out:** This category is the new long-distance transmission lines, and the extra capacity for local distribution required to connect the new supply. The costs are based on known GW-miles/year of existing infrastructure [19, 20].
3. **Household Electrification:** These are all of the components of a national electrification strategy that are connected to households. It includes the appliance upgrades, and electric vehicle upgrades appropriate to complete decarbonization of all households.

4. **Household Efficiency:** These are the more traditional energy efficiency measures for upgrading U.S.residential building stock (insulation, double glazing, new wiring, LED lighting, hydronic heating loops) such that the appliances in Household Electrification can work more efficiently.
5. **Transportation Sector:** This accounts for the replacement of our personal, fleet,and commercial light-duty vehicles (~ 250 million of them) and 6 million trucks.
6. **Commercial Sector:** These are the HVAC, lighting, water, and cooking retrofits required of the commercial building stock estimated on a \$/sq.ft basis. We include public vehicle charging infrastructure under the commercial sector as we anticipate the majority to be in parking spaces adjacent to or located at commercial businesses. We include commercial freight trucking in this sector.
7. **Industrial Sector:** We very grossly estimate the increased capital spending required per industrial sector as a multiplier of the 2017 capital expenditure of U.S. industry to account for the electrification upgrades of process heat and other efficiency measures.
8. **Energy Research and Development:** The plan for decarbonization we outline does not require or reference technologies that do not yet exist; however the project certainly gets cheaper the more we invest in R&D. We use comparable existing R&D budgets from ARPA-e, DARPA, and NSF, to contemplate an annual spend appropriate to an aggressive U.S. decarbonization or energy-led economic recovery program. Energy R&D will be important, particularly in the hard-to-decarbonize sectors of industry, and if there is to be any near-term progress made on “game-changing” technologies such as advanced nuclear, fusion, a breakthrough battery, or carbon capture.
9. **Education and Training:** An enormous amount of education and retraining will be required to mobilize a workforce at this scale. We use the total existing trade and vocational training industry and its annual expenditures to grossly estimate this component.

Once we have each of these estimates, we’ll add them up, reconcile the timeframes of all of the upgrades, and develop a schedule of jobs created per year under the assumption that we will do an aggressive 3-5 year ramp up of manufacturing and installation capacity, followed by a period of implementation with a goal of majority decarbonization by 2035 — commensurate with a goal of avoiding $2^{\circ}\text{C}/3.6^{\circ}\text{F}$ of warming.

Supply Build-Out

The new generation capacity we can guess at pretty well. In [Table 4](#) we create an additional 1500 GW of new capacity, in addition to the 319 GW of net-zero-carbon capacity we already have.

The observant reader will notice that we use a very low cost of rooftop solar of \$1.50. This is half of the current American cost (\$3-3.20/W), and more in line with the costs in Australia — in fact, they vary between \$1 and 1.25/W down-under. It would create more jobs if we used the current U.S. number, but it would make energy more expensive, and

Generation type	$GW_{nominal}$	\$/W	Millions of \$ 2017
WIND	1500	\$1.48	\$2,215,500
SOLAR - rooftop	1000	\$1.50	\$1,500,000
SOLAR - utility	1500	\$1.38	\$2,070,000
HYDRO	75	\$2.00	\$150,000
NUCLEAR	100	\$3.00	\$300,000
GEO	50	\$4.00	\$200,000
BIO	100	\$2.00	\$200,000

Table 4: *New primary energy (Nominal installed capacity to which capacity factors must be applied) that will deliver approximately 1500 net new GW of electricity, and additional biofuels*

Category	GW of capacity	\$M/GW/year	Millions of \$ 2017
Transmission	1000	21	\$21,000
Distribution	1000	52	\$52,000

Table 5: *New Transmission and Distribution*

that is not the goal. We want to create the lowest cost energy system we can, save our households money, and create jobs, but one immediately sees the tension in this approach to the analysis: if you want the answer to be more jobs, spend more money!

This, then, is the total work that needs to be done to decarbonize. It won't happen in a year, so we will need to decide upon the time period over which it is implemented to determine the annual jobs.

We will push on with as much clarity as we can about the cost of things.

Transmission and Distribution Build-Out

Much of this new generation capacity will need to be connected to the grid, and transmitted and distributed. Some of it is biofuels and much of it is rooftop solar that needs neither transmission or distribution. The other 1000 GW needs to be connected though.

We can use existing costs of transmission in millions of dollars per GW of capacity per year. Using the University of Texas, Austin, estimates, we get [Table 5](#). This is an annualized estimate of the number of jobs based on estimates of the current annual costs per GW of capacity.

Household Electrification and Household Efficiency Retrofits

What do we need on the demand side? Let's look at our homes and vehicles first in [Table 6](#). We must account for replacing all of the equipment that currently uses fossil fuels. For example we assume that hot water heaters that are mostly natural gas today are replaced by heat pump water heaters. We assume one per household, but that only about 3/4 of households need one, as many already have electric hot water systems. We assume most houses will need a new load center commensurate with increasing the electrical load in the household significantly. Similar logic is applied to the other appliances in the house.

Number of units (millions)	Item	Decarbonized cost (\$)	Incumbent cost (\$)	Transformation Cost (M\$)
Appliances				
90	HP water heater	1,600	1,130	42,300
100	Load center	2,000	0	200,000
80	HP furnace	7,500	4,000	280,000
100	Home car charger	1,500	0	150,000
80	Induction range	1,200	1,000	16,000
80	Home battery electric	3,000	0	240,000
80	Home battery thermal	1,000	0	80,000
50	Electric Dryer	1,200	1,100	5,000
Retrofits				
1,200	LED Lightbulbs (/bulb)	2	1	1,200
Optional Efficiency Retrofits				
120,000	hydronic heat (/sqft)	10	0	1,200,000
240,000	window retro (/sqft)	7	0	1,680,000
240,000	insulation retro (/sqft)	2	0	480,000
240,000	electric retro (/sqft)	2.5	0	600,000

Table 6: *Upgrading our 120+ million homes. The Optional Efficiency Retrofits are not critical to our analysis.*

Number of units (millions)	Item	Decarbonized cost (\$)	Incumbent cost (\$)	Transformation Cost (M\$)
250	Light duty vehicles	38,000	32,000	1,500,000
5	Freight Trucks	120,000	80,000	200,000

Table 7: *Upgrading our transportation fleet.*

It is assumed nearly every household will have at least one home car charger installed, for example. We include light-duty vehicles under household electrification as they are purchases made by the household, connected to the household, and will be integral to the “electrical infrastructure of the home.” It is not strictly necessary by the methodology we outlined at the beginning of this white paper, but we assume a small number of traditional “efficiency” jobs — insulation and double-glazed windows as canonical examples. Another curious thing will become apparent — as LED lightbulbs are now so cheap and economically effective, and because they last so long, mass adoption will result in fewer net jobs¹³.

Transportation:

As per Table 7 there are between 250 million and 263 million light-duty vehicles. There are 5.5-6 million trucks. We assume a \$6,000 dollar price differential for EV’s and a \$40,000 dollar price differential for alt-fuel (but mostly electric) trucks.

¹³You can imagine what the nay-saying press will have to say about that!

Billion Sq.Ft (of 90 billion total)	Item	\$ / sq.ft	Transformation cost (M\$)
75	HVAC	20	1,500,000
60	Lighting	5	300,000
40	Cooking	1	90,000
80	Water	1	160,000
50	Refrigeration	2	100,000
Units (millions)	Item	Unit cost (\$)	Total cost (M\$)
50	car chargers	6,000	300,000

Table 8: *Upgrading our commercial buildings and charging stations*

Commercial Buildings

Upgrade of commercial buildings is required as well, and we will include public electric car charging infrastructure here. For commercial buildings the calculations are made using gross estimates of the per square foot price of upgrading things like the HVAC systems. We present these top line estimates in [Table 8](#).

Industrial Sector

The final sector of the economy we need to consider is industry, which comprises manufacturing, mining, and agriculture, among others. It’s more complicated to provide a cost estimate for a sector that is so varied. We know that we’ll need new capital expenditures for upgrading steel mills to electric and hydrogen, aluminum smelters, and new ways of making pretty much everything to eliminate the oil, coal, and natural gas that power much of industry.

To produce a very gross estimate we look at the 2019 United States Census Bureau’s “U.S. Capital Spending Patterns 2008-2017” [\[21\]](#). We will take the 2017 capital expenditures by industry sector, and assume capital equipment is turned over during the 15-year mobilization and decarbonization periods (2020-2035) to calculate an expenditure as a multiple of the historic amount. We change this multiple for different sectors with a gross estimate of which will be more impacted. We look at this in [Table 9](#).

Research and Development

For a gross estimate we can begin with analogous existing federal R&D spending. We then estimate how much similar spending might be dedicated to energy system renewal and decarbonization, including the material economy. Today DARPA, The Defense Advanced Research Program Agency — perhaps the most renowned R&D agency in the world for high-risk, high-return research — has a budget of \$3.4bN annually [\[22\]](#). We add a number like that to spending by an agency like ARPA-e, which is modeled on DARPA, but exists specifically to advance high-risk, applied research projects in energy. NSF, the National Science Foundation, currently has a budget of around 8bN [\[23\]](#). The NSF does fundamental

Industry Sector	2017 Cap-Ex Spend (M\$)	Decarbonized Multiplier	Decarbonized Spend (M\$)
Forestry, fishing, & agricultural services	\$4,746	1.25	\$1,186
Mining	\$132,875	1.25	\$33,219
Utilities	\$134,456	1.25	\$33,614
Construction	\$34,800	1.25	\$8,700
Manufacturing	\$248,349	2.00	\$248,349
Wholesale trade	\$42,710	1.10	\$4,271
Retail trade	\$91,747	1.05	\$4,587
Transportation and warehousing	\$110,729	1.05	\$5,536
Information	\$158,184	1.10	\$15,818
Finance and insurance	\$167,675	1.05	\$8,384
Real estate and rental and leasing	\$158,184	1.05	\$7,909
Professional, scientific, & technical services	\$37,964	1.05	\$1,898
Management, companies & enterprises	\$7,909	1.05	\$395
Administrative & support & waste management	\$26,891	1.05	\$1,345
Educational services	\$36,382	1.05	\$1,819
Health care and social assistance	\$104,401	1.05	\$5,220
Arts, entertainment, and recreation	\$22,146	1.05	\$1,107
Accommodation and food services	\$36,382	1.05	\$1,819
Other services (except public administration)	\$22,146	1.05	\$1,107
Industries not elsewhere classified	\$4,746	1.05	\$237
TOTAL INDUSTRIAL UPGRADE ANNUALLY	\$1,581,840		\$509,906

Table 9: *Upgrading our Industrial Capital Equipment*

Agency	New budget	Old budget	Net new Spending
DARPA	\$3,400	\$3,400 [22]	\$0
ARPA-e	\$4,000	\$366 [24]	\$3,634
NSF	\$10,000	\$8,000 [23]	\$2,000
EERE	\$6,800	\$2,400 [24]	\$4,400
EIA	\$250	\$125 [24]	\$125
New R&D spending			\$10,159

Table 10: *New Federal Research and Development Spending*

science for the large part, exploratory work that creates total new avenues and solutions, not just cost reductions. That level of spending is required to develop viable applications of nuclear fission or fusion, develop low-cost carbon sequestration, improve agriculture, and find alternatives to plastics, cements, steel with carbon, and aluminum — all currently high carbon emitters. EERE is the Energy Efficiency and Renewable Energy office of the DOE. It is the most applied of these agencies, meaning the work is typically closer to market. It is where the heavy lifting of near-term response will be, and hence for this exercise we raise the budget from \$2.4bN to \$6.8bN [24]. Finally, the Energy Information Administration, which helps us know what we know about energy and carbon, will double its budget so that we can have increasingly-detailed knowledge about the right problems to solve. We sum up these numbers, and determine the pathway requires around \$10bN annually in new federal R&D spending. This can be compared to the approximately \$100bN that goes into all federal R&D programs annually.

The discussion above is not offered as a recommendation on the best areas for R&D, and often new agencies will have a fresh take and less bureaucracy than old ones, but rather it illustrates the flavors and types and volumes of R&D spending that could deliver some of the breakthrough technologies that would make it easier to decarbonize in the short term and more cost effective in the long term.

Education and Training

From the analysis above it is apparent that the numbers of new jobs created will require major investments in education and training to make it possible to fill all of the jobs. As a very gross first estimate we can take the gross annual spending of trade and technical schools which is \$16bN [25] and dedicate a similar amount to new vocational training specific to the energy industry jobs to be filled. Someone will have to train an awful lot of electrical technicians as only one example of all of the new jobs in this sector.

Finance jobs

This type of program will require a very large volume of monetary transactions, including borrowing and repayment. We use a very simple cost analysis to produce a first-cut rough estimate of the jobs creation in the finance sector. We take the total spending on this project and apply a net present value calculation based on a 20-year amortization and an interest rate of 4%. These annual interest expenditures are converted into a jobs number using the jobs multipliers or factors appropriate to the finance industry: 4.10 direct jobs / \$Million, 3.49 indirect, 10.11 induced, and 17.70 in total.

Adding it all up

The spending from all of these categories can now be added together. We convert all spending into annualized expenditures. This is something like the fastest imaginable pathway to decarbonization without hobbling the economy — in fact, boosting it. The emissions trajectory associated with this level of ambition, if also subsequently carried out by the other major emitters¹⁴, correlates to a 2° C/3.6° F world. In the case of the supply-side build-out this means that we assume an aggressive 3-5 year ramp up of capacity followed by a similarly aggressive 10-year build-out of the capacity. This implies near complete decarbonization of the supply side by 2035. On the demand side we largely try to replace things at the natural replacement rate implied by the natural lifetime of the incumbent technology. For example, water heaters last on average about 11 years, so we spread the spending out over that period. As such the great majority of the demand side will also be decarbonized by 2035. Annualized spending such as R&D and training are treated as such. We use established

¹⁴There is a first-mover advantage to the economies that act this decisively first in producing highly profitable export industries to serve the rest of the world. Proving the economics work for America would provide the majority of other nations with the impetus and a framework for their own decarbonization plans.

Sector	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Electricity supply	170	335	495	488	481	473	466	459	452	446
Grid	49	97	143	141	139	136	134	132	130	128
Residential	15	30	45	59	73	72	71	70	69	54
Residential efficiency	46	95	143	189	234	231	227	224	220	217
Commercial	111	130	149	166	177	175	172	170	167	135
Transportation	26	52	77	102	126	124	122	120	118	116
Industrial	45	90	133	175	216	213	209	206	203	200
R&D	2	4	10	10	10	10	10	10	10	10
Education/training	4	7	16	15	15	15	15	15	15	14
Finance	11	31	59	90	125	158	192	225	257	288
Total:	482	875	1,273	1,440	1,598	1,610	1,622	1,633	1,645	1,612

Table 11: *Total cost of capital, training, and build-out of a zero-carbon US economy in B\$₂₀₁₇.*

sector appropriate job multipliers to calculate the direct, indirect, and induced jobs in the new energy world implied.

The first 10 years of spending is broadly outlined in [Table 11](#).

As per the typical methodology of economists, we convert the dollar amounts in [Table 11](#) to direct, indirect, and induced jobs using indicative sector specific job coefficients. For the majority of these estimates we use the specific coefficients for construction industry of (1) direct: 5.68 Jobs per million dollars, (2) indirect: 3.87 jobs/\$M, and (3) induced: 10.22 jobs/\$M. This represents a total of nearly 20 jobs per million dollars spent. [Figure 8](#) shows the rapid mobilization ramp-up as capacity is built to manufacture and install the necessary infrastructure. New jobs peak after this ramp at about 34 million. As would be expected, the jobs ramp down after the initial infrastructure build-out, and then stabilize long-term. After the build-out period bubble of jobs the number of jobs tapers off to the sustained jobs in the natural rate of turnover in replacement installations and operations and maintenance of the new energy economy, which we can see out to 2040. Technology and automation could change the number enormously — we modeled in an industrial cost reduction rate of 1.5% per year associated with industries still ramping up production in addition to the compounding 1.34% labor productivity improvements associated with mature industries. This cost reduction rate is likely higher in such a mobilization. From where we stand today we can assume the 2040 numbers as the approximate total number of new sustained jobs in a fully transitioned energy economy.

But this does not fully account for the jobs displaced or transitioned in this full decarbonization plan. We need to understand the direct, indirect, and induced jobs in the current fossil economy, and subtract those from our total. We have the choice of 3 different numbers: (1) We can take the estimate from the USEER study, or (2) we can take the direct fossil jobs in the BLS data and multiply by normalized indirect and induced job factors for the energy industry, or (3) take the same BLS data and use the indirect and induced job factors for the construction industry, which was the multiplier for all of the other jobs we analyzed. We chose (2), which totals 1,092,900 direct jobs, for a total of 11,141,090 jobs. We also consider existing non-carbon, non-fossil, energy jobs in the same manner, where the existing 643,770 jobs become 6,562,631 with the same jobs multipliers. All of these jobs are graphed in [Figure 9](#). We can see the tapering out of the fossil-related jobs through 2040, and the

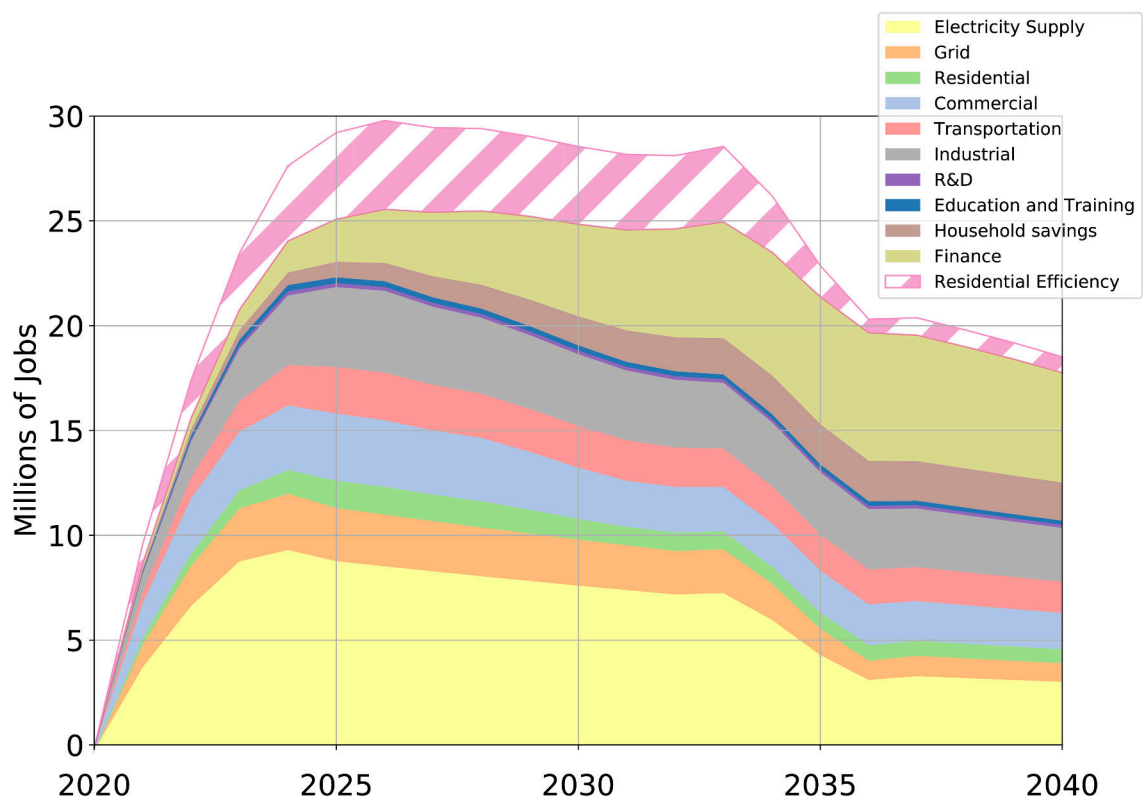


Figure 8: New clean energy jobs created in a mobilization of the economy commensurate with a $2^{\circ}\text{C}/3.6^{\circ}\text{F}$ target. The "efficiency" jobs (pink stripes) are optional, and not necessary for decarbonization and not included in our total job count.

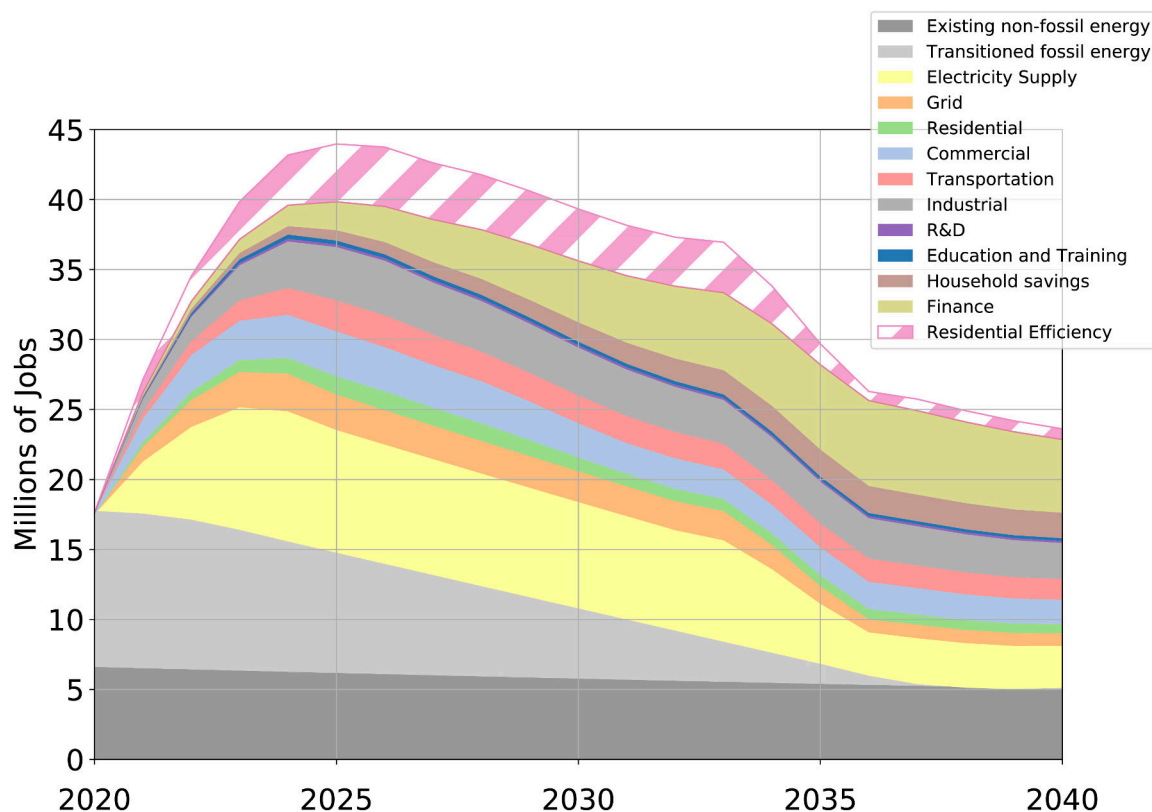


Figure 9: *Total jobs in energy through 2040 with a winding down of fossil fuels and decarbonization effort commensurate with a 2° C/3.6° F target. The “efficiency” jobs (pink stripes) are optional, and not necessary for decarbonization and not included in our total job count.*

fact that they are more than compensated for by the enormous number of new jobs in the new energy economy. It won’t be easy for everyone, and given the vibrant economy we have enjoyed for a century underpinned by these fossil jobs, we believe the argument stands for treating very generously those who have worked in fossil with appropriate re-training and early-retirement programs. With plenty of empathy we should be capable of a manageable transition.

Revenue supporting job creation.

We emphasize once again the potential double-edged sword of these calculations. Because this economics methodology for calculating jobs starts with “dollars in = jobs out” one must resist the temptation to just spend more money to create the number of desired jobs. For example, if this analysis were to use the existing cost of installation of rooftop solar in the U.S., \$3.20/Watt, we create 3.5 million more jobs than if we use something more like the Australian price of \$1.50/Watt. However, if we create those extra jobs, we increase the price of energy because of that extra labor. That potential conflict is everywhere in this analysis. Because LED lighting at this point in history is such an easy economic win — the bulbs last much more than ten times as long and are not nearly ten times more expensive, installing

Sector	Gov.Share	Precedent
SUPPLY BUILD-OUT	26%	RTC credit
GRID BUILDOUT	10%	Tax credit
HOUSEHOLD ELECTRIFICATION	25%	Rebates, loan guarantees
HOUSEHOLD EFFICIENCY	5%	Rebates, incentives
COMMERCIAL SECTOR	5%	tax incentives
TRANSPORTATION SECTOR	30%	Rebates, tax incentives
INDUSTRIAL SECTOR	25%	subsidies / tax incentives
ENERGY R&D	50%	direct
EDUCATION AND TRAINING	50%	direct
FINANCE JOBS	0%	

Table 12: *Estimating Federal contribution by sector*

LED lighting results in spending less money and destroying jobs in these analyses.

We are careful in this analysis to balance both sides of the ledger. This is why we began this analysis discussion with the heuristic of the primary economic driver of job creation on this pathway: it creates net jobs because what would have been paid for in fueling the fossil energy system in the future is used to invest in labor in the manufacturing and installation of a clean energy system that doesn't need fuel in the future.

The other edge of this sword is the temptation to report the total dollar investment required for this pathway, not the savings, and not the economic benefit. However, the government does not pay for the entire program. That is not how it worked in the Great Depression, nor how it worked in WWII. Government programs and incentives and loan guarantees can all be designed to leverage huge amounts of private sector money. Federal loan guarantees of mortgages that were invented in 1936 were designed to provide liquidity to local and regional banks without the government actually having to spend money, but merely guarantee mortgages to improve loan viability. So we now look at the costs of this type of mobilization effort and estimate which costs will be borne by the government and which by the private sector in this ambitious program. We can do a first pass on gross estimates of government vs. private investment by looking at historic methods for motivating the right investments in energy.

We can look in [Table 12](#) for estimates of the government portion by sector. If we look at the first 10 years of spending, through 2031, the federal portion of the spending is \$2.8 trillion dollars of a total \$11.7 trillion dollar investment.

This transition save households money on their energy bills, improves air quality and health outcomes, reduces our emissions to near zero and helps with the global issue of addressing climate change. The roughly \$300 billion dollars per year of government investment is similar to the amount we project households to save on their energy costs should we do this smartly¹⁵.

¹⁵Doing it smartly is never guaranteed with this many interest groups, but hopefully the largest interest group of all, the American consumer and voter, will see the wisdom in building the nation's infrastructure to save every household money.

Historical Parallels

Job creation on this scale and at this pace is not without precedent. The U.S. followed a very similar path in mobilizing for WWII. Winning the war for the Allies had a total cost of around 1.5 1939 GDPs. Transitioning to a completely decarbonized energy system probably has a cost closer to just 1 2019 GDP of \$22 Trillion. We can take a retroactive look at wartime production, recorded in *Wartime Production Statistics and the Reconversion Outlook*, War Production Board, Oct 9, 1945, to see that these projections that look enormous are not dissimilar in their effect on the economy as to what was seen in WWII. In [Figure 10](#) we see the 60-70% expansion of manufacturing employment, the more than doubling of manufacturing output, and the other massive increases in construction and raw materials production required to feed this activity. Even more illustrative is [Figure 11](#) which shows the economy-wide benefits of such an audacious project. An 18.3% increase in the labor force, a 63% increase in manufacturing employment, a 52% increase in Gross National Product, and a massive 58% increase in consumer spending, as so many more people had money in their pockets to spend. The war analogy is not perfect, but it helps in understanding that mobilization of our industrial capacity can drive the creation of millions of new jobs while protecting consumer well-being.

Sheer Scale

Any effort to transform an economy as ambitious as that outlined in this scenario is destined to strain the validity of models based on precedent and historical data. In spite of this, it is a very informative exercise to model this audacious transition to a more verdant and healthier world that protects citizens and environment alike.

Historically, industrialists have been able to estimate the cost reductions of technologies as they scale up according to scaling laws like Moore's law, or Swanson's law. These laws observe that costs reduce predictably with each doubling of the production capacity. If we use the 2019 global production capacity figures for a few of the critical technologies required for this project, we can see that we are a number of doublings away from being able to produce at the sustainable capacity required to provide global clean energy. EVs are on the most accelerated path, and we only need on order of 2-3 more doublings (4X-8X current production rates). For solar, wind, and batteries we are 3-4 more doublings (8X-16X). This has a couple of major consequences: the sheer scale of this project will reduce its cost enormously, and that will be both good for the consumers, but temper some of the higher jobs numbers in this report.

In the most simplistic analysis, only considering jobs in the energy industry, we can see that decarbonization will produce at steady state a few millions more direct jobs than what we are doing today with fossil fuels. In a more complete economic analysis based on the typical methodologies for modeling economy-wide job creation we see the net creation of around 23 million jobs at the peak settling at around 4-6 million more jobs at steady state (2040 and beyond). As with WWII production one can expect that at this scale of manufacturing and mobilization, many more innovations and a lot more automation will be invented and bought to the task, and no doubt this is an estimate on the high side. The

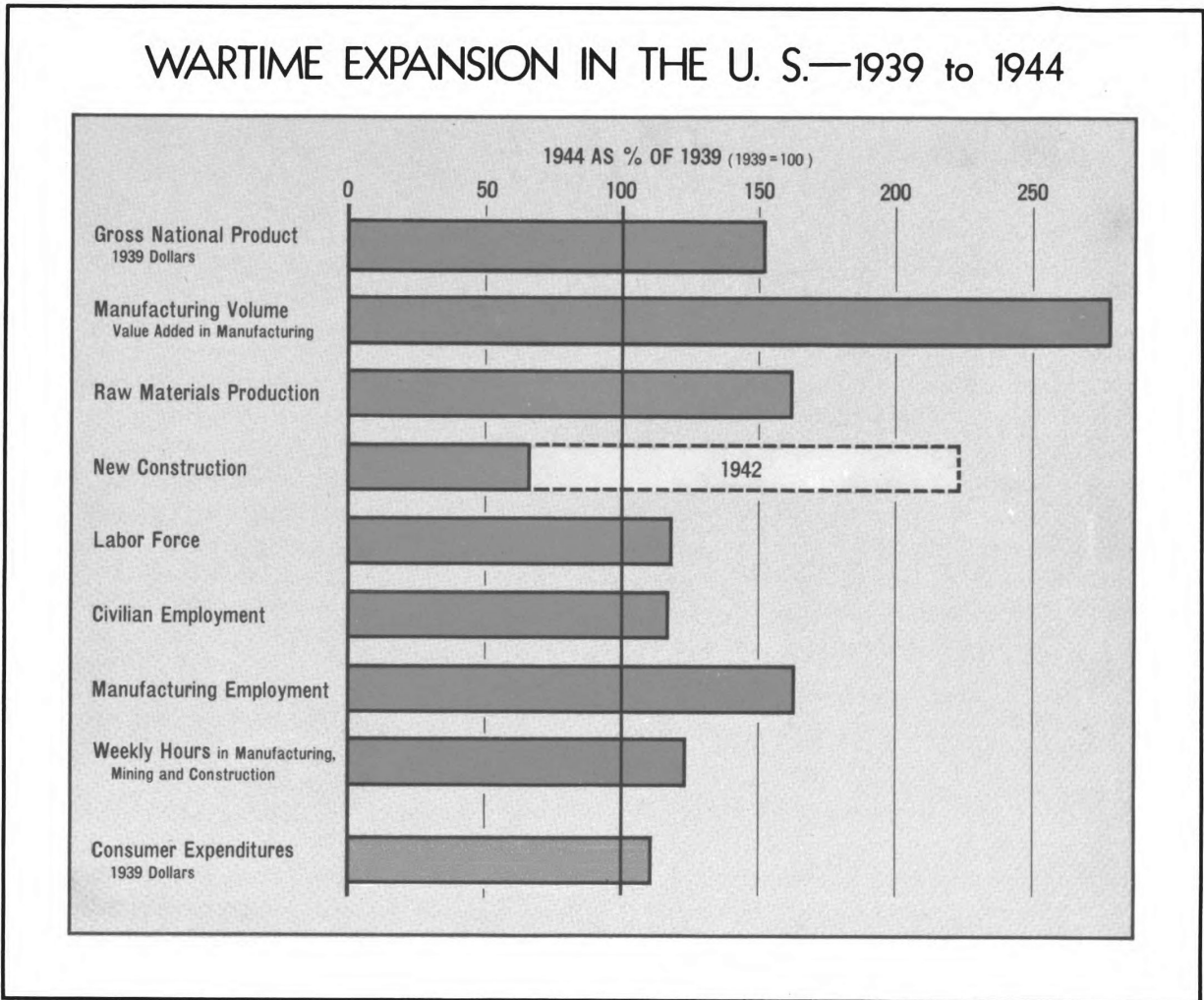


Figure 10: *Net new jobs created in a mobilization of the economy commensurate with a $2^{\circ}\text{C}/3.6^{\circ}\text{F}$ target.*

SOME WARTIME SHIFTS IN U. S. ECONOMY

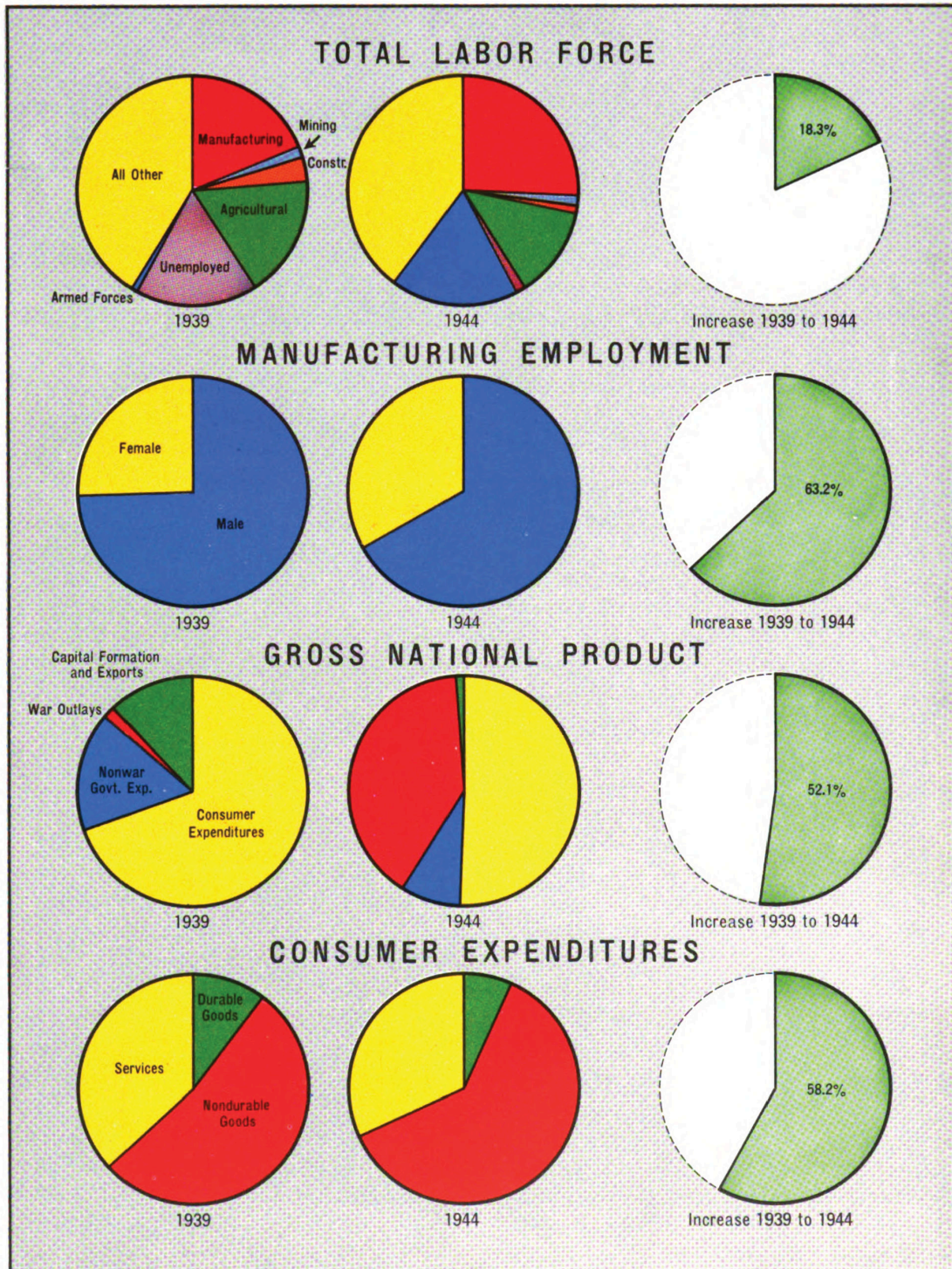


Figure 11: Net new jobs created in a mobilization of the economy commensurate with a $2^{\circ}C/3.6^{\circ}F$ target.

Estimation Source	Supply &/or Demand	Jobs	Direct &/or Indirect
Existing BLS data	Mostly Supply	2,600,000	Direct, some indirect
BLS without gas stations	Mostly Supply	1,800,000	Direct, some indirect
BLS Direct Fossil	Supply only	1,100,000	Direct
USEER	Supply and demand	6,000,000	Direct, Indirect, part time
Jobs/MWh studies	Supply only	4,000,000	Direct
Econometric Analysis	Supply and demand	25,000,000	Direct, Indirect, Induced
Econometric Analysis (w/ efficiency)	Supply and demand	30,000,000	Direct, Indirect, Induced
Econometric, sustained new 2040 jobs	Supply and demand	5,000,000	Direct, Indirect, Induced
WWII, Arsenal of Democracy	Neither	20,000,000	All jobs

Table 13: *Summary of various job estimation methods and number of jobs.*

good news is that with aggressive assumptions about automation and efficiency we would see even greater savings in household energy costs, and still with millions of new, well-paying jobs in the economy.

These estimates here use the current mix of domestic and imported manufacturing as per the data of 2017. With a more “Made in America” policy on the manufacturing side, this analysis would show even greater numbers of domestic jobs in manufacturing. However, the majority of jobs in this proposal to stimulate the American economy and lead the world in clean energy are construction and installation jobs that occur in every zip code. Installing rooftop solar, installing wind farms, replacing furnaces and hot water heaters — these are all jobs that cannot be shipped overseas. These are good jobs that play strongly to the productivity and industriousness of American workers in construction and the trades. A stimulus program along these lines will reap enormous rewards in precisely the areas of the economy that we have ignored for the past four decades: rural areas, small towns, and industrial manufacturing towns.

Summary of methods and results

Table 13 summarizes the data sources and methods, the scope (supply, demand, or both), job creation, and whether the scope is direct, indirect or induced jobs as calculated by different methods in this report.

Level of Decarbonization

What many people want to know is how much decarbonization is achieved by what policies. We have presented the Maximum Feasible Transition to zero carbon (MFT) model. This assumes a massive and rapid build up in industrial capacity akin to the Arsenal of Democracy for WWII. After this 5 year period we assume that industrial capacity is sufficient to meet a 100% adoption rate for all key carbon producing technologies, e.g. EV’s, heat pump furnaces, heat pump water heaters, induction ranges, solar, wind and nuclear power plants, electric trucks, rooftop solar, etc.

It is beyond the scope of this modelling to determine the exact levels of decarbonization by sector. We can estimate decarbonization grossly, by understanding the lifetime of the current

fossil powered equipment that will be replaced, and their gross replacement schedules. We can look to EIA data[26] for estimating the level of grid decarbonization over this timeframe by inferring which generation capacity will be replaced or retired. Limited studies of the histogram of vehicle ages[27], and of the age distributions of home appliances[28] can be used to guess at what portion of those machines can be replaced by 2035 on a 100% adoption rate schedule as per MFT.

A snapshot: Furnaces last on average around 15-20 years. Water heaters 10-12. Most power plants 30-50. Cars have an average age of 12 years, but as we know there are a lot of 25 year old cars on the road.

Hence we can very grossly estimate the following levels of decarbonization by sector for the year 2035, on the JOBS pathway:

- Residential 75-95%, limited by the retirement of natural gas heating (of hot water, air and food).
- Commercial 75-95%, limited by the retirement of natural gas heating (of water, air and food).
- Industrial 60-80%, limited by our capacity to invent the technologies to decarbonize the difficult to decarbonize sectors such as steel, aluminum, paper and pulp, and plastics.
- Transportation, 80-90%, limited by the long tail of older vehicles being kept on the road as well as non-highway transportation innovations in things like the decarbonization of flying.
- Electric grid, 70-80%, limited by the recently built natural gas plants, and any coal we can't retire for political reasons on this timeframe. The proportion of total electric grid will be much higher as we need to increase the output of the grid approximately 3-fold in this period to absorb the level of electrification of our vehicles, residences and businesses, and that extra capacity is assumed to be from new-build non-combustion sources.

To be clear, continuing down this pathway will decarbonize close to 100% of everything by 2050 and the levels above are professional estimates of best case adoption rates by 2035.

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Valuable contributions to the methodology and economic analysis were made by Skip Laitner¹⁶. Contextual material on climate and excellent editing was added by Hunter Cutting¹⁷. Content and style reviews were made by Adam Zurofsky¹⁸. Critical edits making this a human-readable document were made by Laura Fraser.

¹⁶Economic and Human Dimensions Research Associates

¹⁷Climate Nexus

¹⁸Rewiring America

End notes on this decarbonization pathway

1.5 degrees C of warming is the IPCC’s aspirational target for climate change. This target does not consider at least three practical problems. First, since 2004 the IPCC has assumed significant negative emissions by carbon sequestration. We believe they are highly unlikely to be real as the energetics, kinetics and cost of carbon dioxide removal are so poor. We cannot rule out a breakthrough, but it is even more true that we shouldn’t model it in as assumed [29]. It must be remembered that as a single man-made substance, humanity produces more CO₂ than it does *all other materials combined*. In 2019 the US manufactured around 6.5 billion tons of agricultural products, fossil fuels, meta ores and non-metallic minerals. We emitted 6.7 billion tons of CO₂.

Second, this 1.5° C/2.7° F target considers “committed emissions,” or the emissions that will be emitted by infrastructure already built or planned to be built. This consideration is why early retirement is modeled in to emissions trajectories, as committed emissions already put us on a trajectory somewhere in the middle of 1.5° C/2.7° F and 2° C/3.6° F . This policy emphasis on early retirement of the heaviest emitters (coal) is good and sound policy, but often politically poisonous as it implies specifically abruptly closing down coal plants and mines. The implication of the committed emissions trajectories is that if every country in the world merely had 100% adoption rates of zero-carbon technology starting today, we would end up with around a 1.75 degree world.

Third, none of the targets we use consider the time required to ramp up the industries necessary to create the solutions. If we just look at electric vehicles, batteries, wind turbines, and solar modules, each need an increase in production quantity of one order of magnitude or greater. This is 3 or more doublings of the current capacities. Even with something akin to the U.S’ WWII production ramp-up, but this time globally, this would take 5 or more years.

If the other major manufacturing nations, China, Germany, Japan, and South Korea all follow suit in short order, and if nations that are unlikely to decarbonize quickly due to their fossil reserves and politics (eg. Russia, Saudi Arabia, Brazil, Nigeria) are slower to respond, it is safe to say that this is probably the only strategy with technology that is known today that can hit a roughly 2 degree target given climate sensitivity uncertainties. Early retirement of our heaviest emitters (coal fired electricity) can improve this picture a little bit.

Additional Thoughts

Jobs vs. Cost

The traditional pathways to lowering the cost of manufactured goods is either through manufacturing automation, which negatively affects the labor market, or through off-shoring to a country with lower wage rates and fewer environmental regulations — both with negative societal outcomes. We want cheap energy, we want cheap goods, and we want well-paying jobs. There is an obvious conflict here between these things. Domestic manufacturing is probably the best pathway for any country looking to build these industries, but it is likely

achieved with very high levels of automation. Fortunately this only affects the manufacturing job component, which is small compared to the installation and maintenance labor. Decreasing manufacturing jobs due to automation can be more than compensated with increasing export markets for the early national adopters of these categories of climate solutions.

6 days, 5 days, 4 days

America pioneered the cultural move from a 6-day work week to a 5-day work week through the middle of the 20th century. With enormous productivity improvements since the industrial revolution, this was possible without undue economic impact. A counter argument to those who oppose high levels of automation is that it could be our pathway to a 4-day work week. For why do we work if not to enable some leisure?

References

- [1] Max Wei, Shana Patadia, and Daniel M Kammen. “Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?” In: *Energy policy* 38.2 (2010), pp. 919–931.
- [2] US War Production Board. “Wartime Production Achievements and the Reconversion Outlook”. In: *Report of the Chairman, War Production Board* (1945).
- [3] MH Langholtz, BJ Stokes, and LM Eaton. “2016 Billion-ton report: Advancing domestic resources for a thriving bioeconomy, Volume 1: Economic availability of feedstock”. In: *Oak Ridge National Laboratory, Oak Ridge, Tennessee, managed by UT-Battelle, LLC for the US Department of Energy* 2016 (2016), pp. 1–411.
- [4] Dan Tong et al. “Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target”. In: *Nature* 572.7769 (2019), pp. 373–377. DOI: [10.1038/s41586-019-1364-3](https://doi.org/10.1038/s41586-019-1364-3). URL: <https://doi.org/10.1038/s41586-019-1364-3>.
- [5] U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018*. Tech. rep. 2020. URL: <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018>.
- [6] Mark Z Jacobson et al. “100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world”. In: *Joule* 1.1 (2017), pp. 108–121.
- [7] Christina Romer. “Spurious volatility in historical unemployment data”. In: *Journal of Political Economy* 94.1 (1986), pp. 1–37.
- [8] Robert M Coen. “Labor Force and Unemployment in the 1920’s and 1930’s: A Re-examination Based on Postwar Experience”. In: *The Review of Economics and Statistics* (1973), pp. 46–55.
- [9] U.S. Bureau of Labor Statistics. *Labor Force Statistics from the Current Population Survey*. 2020. URL: <https://data.bls.gov/timeseries/LNS14000000> (visited on 05/25/2020).

- [10] The Solar Foundation. *10th Annual National Solar Jobs Census*. 2020. URL: <https://www.thesolarfoundation.org/wp-content/uploads/2020/03/SolarJobsCensus2019.pdf> (visited on 07/01/2020).
- [11] U.S. Energy Information Administration. *Electric Power Monthly*. 2020. URL: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_1_01_a (visited on 07/01/2020).
- [12] U.S. Bureau of Labor Statistics. *Current Employment Statistics*. Tech. rep. 2020. URL: <https://www.bls.gov/ces/data/home.htm>.
- [13] Richard Scarry. *Richard Scarry's What Do People Do All Day?* Golden Books, 2015.
- [14] National Association of State Energy Officials and the Energy Futures Initiative. *2020 U.S. Energy and Employment Report*. Tech. rep. 2020. URL: <https://www.usenergyjobs.org/s/USEER-2020-0323.pdf>.
- [15] U.S. Department of Energy. *Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure*. Tech. rep. 2015. URL: <https://www.energy.gov/policy/downloads/quadrennial-energy-review-first-installment>.
- [16] U.S. Department of Energy. *Quadrennial Energy Review: Transforming the Nation's Electricity System*. Tech. rep. 2017. URL: <https://www.energy.gov/policy/downloads/quadrennial-energy-review-second-installment>.
- [17] National Renewable Energy Laboratory U.S. Department of Energy. *JEDI: Jobs and Economic Development Impact Model*. Tech. rep. 2015. URL: <https://www.nrel.gov/docs/fy15osti/64129.pdf>.
- [18] LLC. IMPLAN Group. *IMPLAN Data 2017*. Tech. rep. Huntersville, NC., 2017. URL: <https://implan.com/>.
- [19] University of Texas at Austin Energy Institute. *Executive Summary: The Full Cost of Electricity*. Tech. rep. 2018. URL: https://energy.utexas.edu/sites/default/files/UTAustin_FCe_Exe_Summary_2018_09_19.pdf.
- [20] University of Texas at Austin Energy Institute. *Trends in Transmission, Distribution, and Administration Costs for U.S. Investor Owned Electric Utilities*. Tech. rep. 2016. URL: https://energy.utexas.edu/sites/default/files/UTAustin_FCe_TDA_2016.pdf.
- [21] U.S. Census Bureau. *2019 Capital Spending Report: U.S. Capital Spending Patterns 2008-2017*. Tech. rep. 2019. URL: <https://www.census.gov/library/publications/2019/econ/2019-csr.html>.
- [22] U.S. Defense Advanced Research Projects Agency. *Budget*. 2020. URL: <https://www.darpa.mil/about-us/budget> (visited on 05/25/2020).
- [23] U.S. National Science Foundation. *Final Action Completed on Appropriations for FY19*. 2020. URL: https://www.nsf.gov/about/congress/116/highlights/cu19_0222.jsp (visited on 05/25/2020).
- [24] U.S. Department of Energy. *FY 2020 Congressional Budget Justification*. 2020. URL: <https://arpa-e.energy.gov/sites/default/files/ARPA-E%5C%20FY%5C%202020%5C%20Budget%5C%20Request.pdf> (visited on 05/25/2020).

- [25] IBISWorld. *Trade and Technical Schools Industry in the US - Market Research Report*. Tech. rep. 2019. URL: <https://www.ibisworld.com/united-states/market-research-reports/trade-technical-schools-industry/>.
- [26] U.S. Energy Information Administration. *Today In Energy*. 2011. URL: <https://www.eia.gov/todayinenergy/detail.php?id=1830> (visited on 07/01/2020).
- [27] Matthew Kahn and Lucas Davis. “International Trade in Used Vehicles: The Environmental Consequences of NAFTA”. In: *American Economic Journal: Economic Policy* 2 (Jan. 2009), pp. 58–82. DOI: [10.1257/pol.2.4.58](https://doi.org/10.1257/pol.2.4.58).
- [28] Lawrence Livermore National Laboratory. *Using National Survey Data to Estimate Lifetimes of Residential Appliances*. 2011. URL: <https://www.osti.gov/servlets/purl/1182737> (visited on 07/01/2020).
- [29] Kurt Zenz House et al. “Economic and energetic analysis of capturing CO₂ from ambient air”. In: *Proceedings of the National Academy of Sciences* 108.51 (2011), pp. 20428–20433.

Are EV Batteries Recyclable?

July 27, 2022 | 4:15 pm

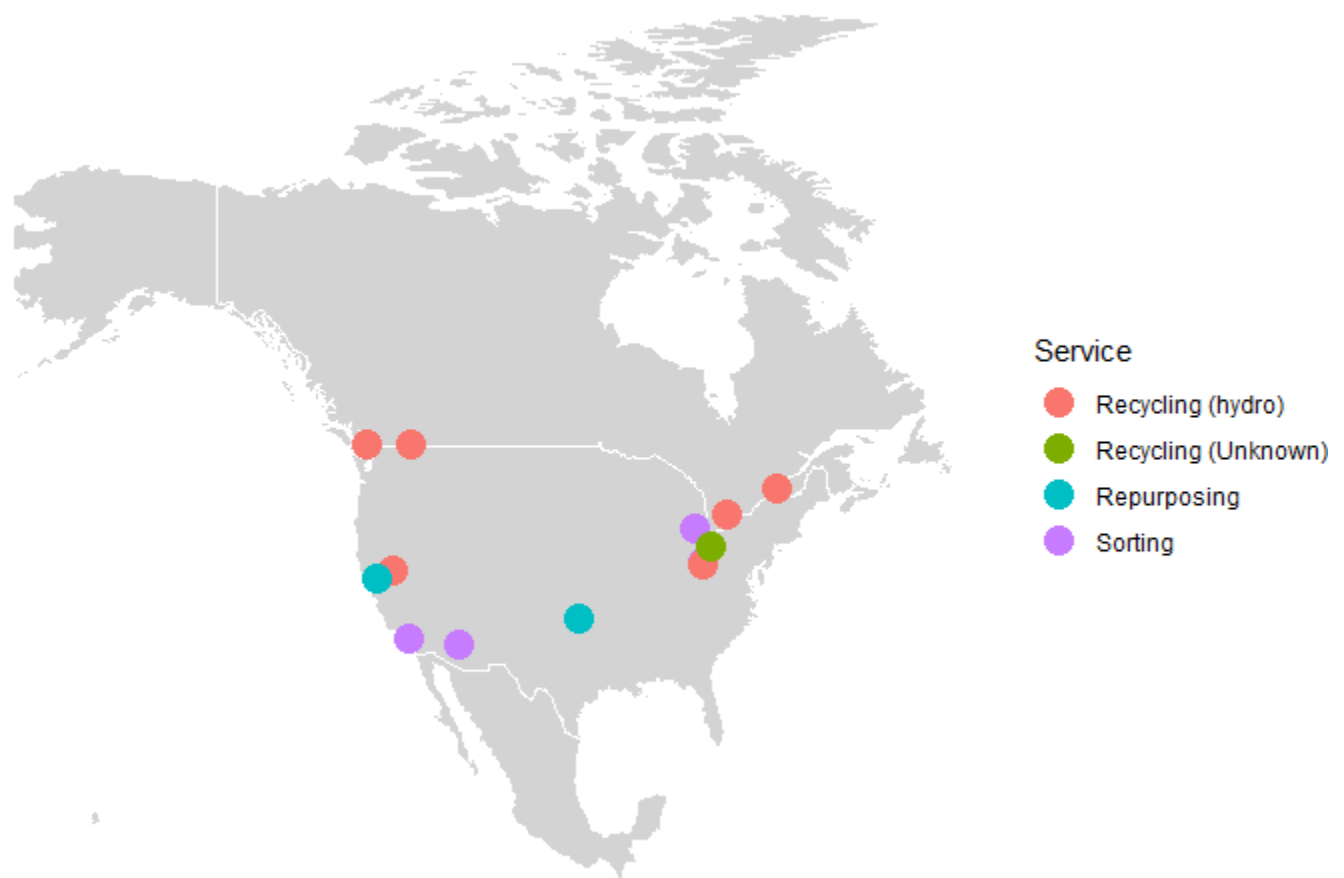


Jessica Dunn
Senior Analyst

As electric vehicle (EV) sales continue to increase, questions about how these cars and their batteries will be disposed of have been top of

mind for current owners, future buyers, policymakers, and many experts in the automotive industry.

EVs are a newer technology, and their batteries require different end-of-life processing than gasoline vehicles. Luckily, lithium-ion battery recycling research and development has been going on for years and there is an existing and growing repurposing and recycling system in North America for these components. The map below is from [recent research](#) that explores the network of companies already recycling and repurposing batteries – these include recycling companies such as [Redwood Materials](#), [Li-Cycle](#), and [Ascend Elements](#). The industry is quickly growing capacity for future recycling, with planned facilities in Nevada, New York, and Georgia, to name just a few.



Current lithium-ion battery collection, repurposing, and recycling network in North America.

[Slattery et al. \(2021\)](#).

First reused and repurposed, then recycled

After a battery's first life in a car and before it is recycled, it can be reused, refurbished, and repurposed.

If the battery isn't damaged during its use in an EV, such as in a car accident, these batteries have additional usable capacity – an estimated 80% of the original rated capacity. This means that if the battery was manufactured to store 100 kWh, it can now store up to 80 kWh. In order to make use of the remaining capacity, the batteries can be broken down to salvage smaller components for reuse and refurbishment, or they can be repurposed and used in a less demanding application, such as [stationary storage](#).

For stationary storage, companies such as [RePurpose Energy](#) and [B2U Storage Solutions](#) are repurposing these batteries to be used for renewable energy generation support. They connect multiple EV batteries together, along with battery monitoring and cooling technology, to create a larger battery that is about the size of a shipping container. The battery stores solar electricity generated during the day and supplies electricity at high-demand times in the evening. As the grid becomes cleaner, added grid storage becomes more necessary to support the generation variability of renewable sources. These used batteries are a great way to both extend the lifespan of a product that has already been manufactured and [support the renewable energy transition](#). After this second-life use, the batteries are then ready to be recycled.

What's valuable in a vehicle battery?

Lithium-ion batteries contain many valuable materials worth recovering and saving from a landfill.

Prior to recycling, the battery is disassembled and shredded using large machinery, breaking the battery into small pieces. Once the shredding is completed, the materials are sifted and separated based on size. This divides them into three different categories: plastics, ferrous materials, and non-ferrous materials (also called black mass). The black mass consists of the critical materials, cobalt, lithium, nickel, and manganese, which can individually be recovered using a hydrometallurgical process.

Hydrometallurgical recycling begins with leaching to create a solvent that contains the critical materials. The individual materials are then recovered using solvent extraction, precipitation, and purification. Hydrometallurgy is well known in the metals industry as a similar process is also used to extract the materials from ore after it is mined. Many US-based lithium-ion recycling companies use a variation of this process and report a material recovery rate of 95%–98%.

Can we use recycled materials to manufacture new batteries?

Yes! Once materials have been recovered, they can then be processed and used in the manufacturing of new lithium-ion batteries. This is a preferable source to using virgin ore because it reduces the amount of mining necessary to produce EVs.

Recent [research](#) has shown that by 2050 recycled materials could supply 45–52% of cobalt, 22–27% of lithium, and 40–46% of nickel used in the United States light- and heavy-duty vehicle fleet. Efforts across the United States to increase the sales of EVs are underway – places like California expect to have 100% of all car sales be electric by 2035 – so being able to recycle batteries and reuse the metal within them is a critical step in the transformation to a cleaner transportation system.

Recycling is key to making EVs greener

EV batteries currently represent about half of the lithium-ion batteries (by mass) that are being recycled, which also includes consumer

electronics and waste from battery manufacturing. With [3.8 million](#) EVs on the road today in North America and sales growing year over year, the number of EVs retiring in coming years will continue to increase as they eventually are totaled or age out of the fleet.

This increase will result in vehicle batteries comprising a much higher percentage of the recycling stream; [retirements](#) are expected to be 6 to 7 times higher in 2025 than in 2020 and 20 to 40 times higher in 2030. Companies recycling these batteries are setting themselves up to accommodate this upcoming wave by expanding their capacity.

These recycling companies are securing a battery stream by partnering with auto manufacturers. For example, major automakers are partnering with Redwood Materials, a recycling company based in Nevada. Redwood is not only recycling but will soon be [closing the material loop](#) by manufacturing battery components with recovered materials.

Redwood Materials has also implemented a recycling program to learn more about the location of retired and uncollected batteries, and how to decrease the costs of transporting these batteries to the recycling facility. Transportation from their location of retirement to the recycling plant is expensive, representing about [50-60%](#) of the recycling costs. These costs are due to the special packaging and requirements needed for shipping retired batteries and their large size and weight. But, transportation costs can potentially be decreased if a more efficient collection system is developed.

Researchers have been modeling potential [reverse logistics networks](#) and now Redwood Materials is completing research of their own through a learning-by-doing approach. Their new [Recycling Program](#) consists of picking up and recycling any retired lithium-ion battery in California at no cost. They are also working with dealerships and dismantlers in order to collect as many batteries as possible.

California is considering battery recycling requirements

As you can see, there is a lot happening in the industry space. And while there is currently no recycling requirement in the United States, California passed a bill that indicates recycling may be a priority for the state.

[Assembly Bill 2832](#) passed in 2018 creating the California Battery Recycling Advisory Group. This group consists of automotive and battery manufacturers, government agency representatives, and public interest groups. They recently [recommended](#) policies to the legislature that could increase the recycling of EV batteries. These recommendations included the creation of a California State requirement that batteries be recycled, holding the auto manufacturer responsible for ensuring that happens. This is not unlike how [mattress, paint, and carpet](#) disposal is currently regulated within California.

In addition to the California work, the federal government is also paying attention. In the [Bipartisan Infrastructure Bill](#), funds were allocated toward battery recycling research and development. This is in addition to the funding of the [ReCell Center](#), a lab created by the Department of Energy that is focused on decreasing costs and increasing yields of recycling.

Battery end-of-life is very important for ensuring that batteries are safely disposed of and that materials are recovered and used again in battery manufacturing. While there is a lot going on to push forward the uptake of EVs and replace gasoline cars for good, many people are simultaneously working to make sure that EV batteries are being reused, repurposed, and recycled.

Posted in: [Transportation](#)

Tags: [electric vehicles](#), [lithium ion batteries](#), [Recycling Clean Energy Technologies](#)

Battery State of Health – What is It? Why is It Important?

October 7, 2022 | 8:00 am



Jessica Dunn
Senior Analyst

Lithium-ion batteries are efficient, compact, and have a long lifespan – all factors that enable electric vehicles (EVs), which are powered by these batteries, to be a great substitute for their gasoline counterpart.

Transportation is a large contributor to greenhouse gas emissions. By [switching to EVs](#), and away from these highly polluting gasoline vehicles, a huge reduction in planet-warming emissions is possible.

While these batteries are revolutionary, they don't last forever. As years pass, and as the batteries charge and discharge, their storage capacity begins to slowly reduce. This is a normal process that is influenced by factors such as temperature, number of cycles, and depth of discharge. Knowing how much life is left in an EV battery is pretty critical for someone who is buying a used EV and for deciding if a battery should be reused, repurposed, or recycled when the EV is retired.

Similar to gasoline vehicles, an EV is expected to last between 8-15 years, at which point the battery will likely have between 70-80% of its capacity left. While this reduced capacity is not ideal for use in an EV, it can continue to be utilized in a second-life application such as stationary storage. Stationary storage is a vital part of the renewable energy transition. The batteries help smooth the supply of renewable generation, such as solar, to meet energy demand. This is done by charging the batteries during the day, when the sun is out, and then using the energy in the evening.

In order to determine if the battery is suited for a second-life application, the state of health must be assessed. **The battery state of health is a measurement that indicates the level of degradation and remaining capacity of the battery.** It is essentially the difference between the health of a new battery and the health of a used battery, and typically represented as a percentage of its initial capacity.

The iPhone is a great example of how we interact with battery state of health in our daily life. Most of us have had the experience of noticing that over time our phone battery cannot hold a charge for as long. Apple got wind of this frustration and now includes a 'Battery Health' indicator in the settings. This communicates the battery's percent maximum available capacity in comparison to when the phone was new.

3:22



[← Battery](#)

Battery Health

Phone batteries, like all rechargeable batteries, are consumable components that become less effective as they age. [Learn more...](#)

Maximum Capacity

82%

This is a measure of battery capacity relative to when it was new. Lower capacity may result in fewer hours of usage between charges.

Peak Performance Capability

Your battery is currently supporting normal peak performance.

Optimized Battery Charging



To reduce battery aging, iPhone learns from your daily charging routine so it can wait to finish charging past 80% until you need to use it.

Screenshot of the author's iPhone battery's state of health.
J. Dunn/UCS

The importance of information sharing

State of health has emerged as an important indicator throughout the lifespan of the battery. When the vehicle is on the road, EV owners want to know the reliability of their vehicle. When owners resell, battery state of health information can more accurately value the product and purchasers can have increased confidence in the EV's worth, longevity, and range. When the EV is retired, knowing the battery's state of health is essential for determining if the battery is viable for reuse and repurposing, or if it should be sent directly to [recycling](#).

Currently, EV battery state of health information is only sometimes accessible at these points along the battery life cycle, and that's not good enough.

While the battery is in the vehicle, the EV owner can view their available range on the dashboard or download an [app](#) on their smartphone which predicts the state of health for some EV models. In addition, auto manufacturers can access further information through the onboard diagnostic system, a proprietary technology that is only available at certified mechanics. When the EV is retired, things get especially tricky. If the vehicle can't be turned on, or if the battery has already been removed, the automaker's state of health estimation can only be accessed via a proprietary connector that is not available at a mechanic, or for purchase.

So, how is state of health determined by repurposers?

Repurposers typically receive batteries that have already been removed from the vehicle. They purchase these batteries with the hope that they have adequate capacity for a second-life application but there is uncertainty about their state of health. If there is no visible damage to the battery, then the state of health is tested. This is typically

completed by monitoring a full charge and discharge – a process estimated to take about [four hours](#).

Several research labs and startups have identified this process inefficiency and are developing technology that can be used to estimate the state of health. [Repurpose Energy](#), a battery repurposing start-up that evolved out of UC Davis, has reported that they developed technology that can estimate the state of health of the previous generation Nissan Leaf batteries within 15-20 minutes. This estimation is model-driven and done by collecting data points during the testing process. This technology must be designed differently for each pack type – even for the newer Nissan Leaf batteries – due to the lack of standardization.

The California Advanced Clean Cars II regulation

California has already identified the sharing of battery health information to the EV owner as essential. The [Advanced Clean Cars II](#) regulation, the most recent version of clean air rules for passenger vehicles, includes requirements for a [standardized state of health indicator](#) that is displayed on the dashboard and available via a standardized connector for EVs produced in 2026 and thereafter. This indicator will increase consumer awareness and trust in the product, **but the regulation stops short of requiring access to the indicator after the battery is out of the vehicle.**

This shortcoming was also pointed out by the [California Lithium-ion Battery Advisory Group](#), a group of stakeholders that was convened by [Assembly Bill 2832](#). They identified this as a missed opportunity to advance the reuse and repurposing of batteries and make them more cost-competitive with new stationary storage batteries.

Why should the state of health be available once the battery is removed?

When batteries are retired from use in an EV, they should be routed to the most efficient next use. These batteries are a huge asset in the renewable energy transition and making the process for their reuse

and repurposing run smoothly can decrease unnecessary costs. Reuse and repurposing are also essential aspects in increasing battery sustainability. They prolong the lifespan of batteries already in circulation and potentially offset the need for new batteries to be manufactured.

Currently, repurposers are spending time and money developing technology to determine information already accessible to automotive manufacturers. In addition, there are parties involved in this process, such as automotive dismantlers, that don't have access to state of health information and are therefore unable to properly value the battery or determine the best next use.

The battery end-of-life industry can greatly benefit by being able to easily access state of health information after the battery is removed from the vehicle. The battery management system within the EV holds this valuable information, and by providing access through a standardized connector, the second-life industry could increase the efficiency of repurposing and potentially the safety, reliability, and consumer trust of the repurposed products.

Posted in: [Transportation](#)

Tags: [Battery Electric Vehicle](#), [lithium ion batteries](#), [Mining](#), [reduce reuse recycle](#)

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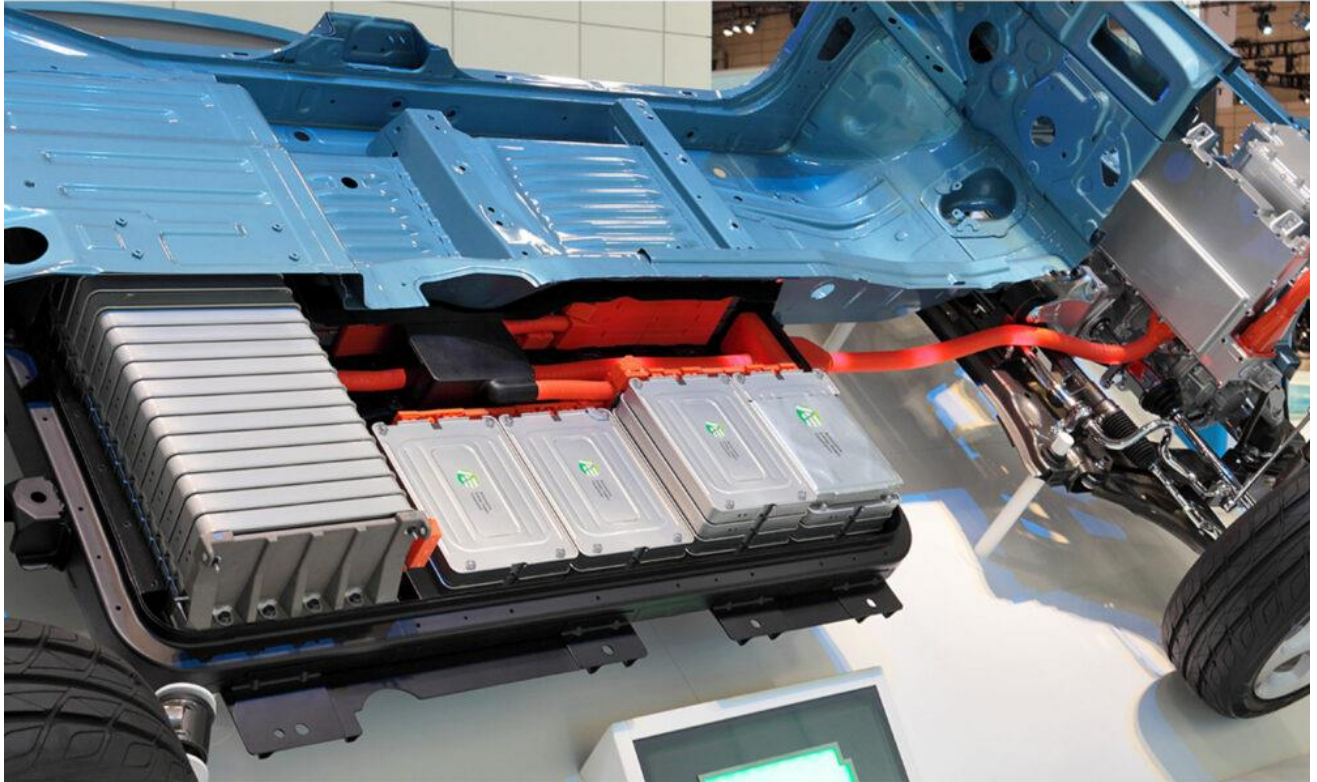
About the author

[MORE FROM JESSICA](#)

Jessica Dunn is a senior analyst in the Clean Transportation Program, specializing in lithium-ion battery sustainability. She conducts research on material circularity and reducing battery impacts through repurposing and recycling.

California's Progress Toward Recycling Policy for EV Batteries

September 20, 2022 | 2:49 pm



Jessica Dunn
Senior Analyst

As electric vehicle (EV) policies are implemented around the country, and sales continue to rise, a question many ask is if vehicle batteries are [recycled](#).

Yes, EV battery recycling is happening in facilities around the United States. The materials recovered, including cobalt, nickel, lithium, and manganese, can be used in the manufacturing of new batteries. While this recycling market is growing, there is still no federal or state law or policy that requires it – an obligation that could ensure higher recycling rates and increased efficiency.

California is taking steps to change that.

In 2019, the state convened a group of experts and stakeholders – thanks to [Assembly Bill 2832](#) – to develop policy recommendations that would increase EV battery recycling. That stakeholder group informed a recently released [report](#) containing policy recommendations for the state.

The report outlines a package of policies that could become the first lithium-ion US battery recycling regulation – including producer responsibility for battery recycling. While this is a huge win for those of us who want to see batteries recycled, there were also a handful of policies that could make incredible strides towards increasing the sustainability of batteries but weren't recommended.

I had the privilege of cofacilitating this group with my colleagues at the University of California, Davis along with some dedicated people at CalRecycle and the Department of Toxic Substance Control. So let me provide a (very) brief summary of the policy recommendations and some insights I gleaned.

Who were the members of the Advisory Group?

The Advisory Group had a final count of [19 members](#) and consisted of representatives from the automotive and battery industries (6 members), waste industry (5 members), public interest organizations (3 members), and government agencies (5 members).

The final policy recommendations were based on a group vote which the government agency representatives recused themselves from. The voting members were, therefore, industry-leaning, with the automotive and battery industry representing 43% of members, the waste industry representing 36%, and the public interest organizations representing 21%. Each policy had to receive an affirmative vote by at least 50% of the group to be included as a recommendation in the report.

Did the group propose recycling requirements?

The group recommended that battery recycling be a requirement in the state and defined the party responsible for covering the costs of transporting and recycling batteries once a vehicle is retired. If this type of policy is passed it could be a great step towards increasing EV battery recycling.

Two policy options to determine the responsible party were proposed. The first says it should be the EV manufacturer (that is, the automaker like Ford or Tesla) who is responsible for ensuring their vehicles' batteries are recycled when the car or truck is no longer on the road. This policy, called extended producer responsibility, was recommended with 67% support from voting members. The automotive companies were the only members to not support this policy, although Tesla was the outlier and in favor of this policy option.

The second option received a greater level of support at 93%. All members voted in favor of this policy, except Tesla who abstained. This second policy option defines the EV manufacturer or an automotive dismantler as the responsible party, depending on a few important factors. These factors require some nuanced knowledge about what happens to a car when it is retired under different circumstances, such as if the vehicle fails under warranty, if it needs the battery to be replaced while out of warranty, or if it crashes or ages out of usefulness. The most common route of retirement is from crashing or getting old, so that will be the version of this policy explained here.

The proposed policy states that if the automotive dismantler (also known as an automotive recycler) acquires the EV and removes the battery, the dismantler is now responsible for making sure the battery is recycled.

To provide some background, after a car is retired, it typically goes to an automotive dismantler. These are certified facilities that take cars apart to sell the parts for reuse or recycling. The disassembly of EVs is very different from the disassembly of gasoline vehicles, therefore new equipment, training, and recycling partners are necessary for dismantlers to handle this new type of vehicle. These dismantlers range from small businesses to corporations, and their trade group, the United Recyclers Group, alone represents over 800 businesses in North America.

An automaker representative explained in an Advisory Group [meeting](#) that they support this policy instead of option 1 due to the potential value of the used EV. Batteries contain valuable materials like cobalt, nickel, and lithium, but some battery chemistries contain more of the valuable materials than others. If the dismantler disassembles the EV and does not want the remaining battery, it is likely the battery has a chemistry that is of lower value and will therefore be a burden to get rid of, instead of a net benefit. So, the auto manufacturer is essentially making sure they do not risk being responsible for an EV that has already been picked apart for valuable pieces and then left with a product that will be costly to dispose of.

What other policies were recommended?

There were three other areas that the advisory group recommended policies: increased access to information, support for industry development, and safe and efficient reverse logistics.

Providing access to battery information while the battery is in the car and after it is removed is crucial to enable efficient and safe reuse, repurposing, and recycling. It was recommended that a label for batteries be required on all EVs and that it include information such as chemistry, capacity, and automotive manufacturer. Labeling EV

batteries is not currently a common practice and makes it difficult to sort the batteries and evaluate the cost (or revenue) of recycling.

In addition to a label, the group recommended vehicle owners – whether that be an ordinary EV driver like you or me, or the dismantler who took the car after it was retired – have access to their battery’s state of health information, or in other words, the leftover capacity and reusability of the battery. This is important in determining if the battery should be reused or repurposed, or if it should be sent directly to recycling. Since this information is not easily accessible, batteries must be fully tested through a full charge and discharge to know the battery’s health. This is a time-consuming and expensive process that can be greatly improved by the sharing of information.

The Advisory Group recommended several policies which would support repurposing and recycling industry development. These policies include recycling incentive packages, expanding grid stationary storage incentives to include repurposed batteries, and expediting the permitting process for recycling facilities in California.

Most policies recommended by the group fell under the safe and efficient reverse logistics category. The group recognized that the high cost of transporting batteries after they have been removed from a vehicle is a large barrier to efficient and cost-effective recycling, representing 50-60% of costs. Some of the reverse logistics policies recommended include supporting research on collection and sorting networks, developing training materials for workers, lessening regulatory barriers to reusing or repurposing transporting batteries, and increasing regulations on EVs sold at auction.

Category	Recommended policies
Responsibility for battery at the end-of-life	• Core exchange and vehicle backstop • Producer take-back
Access to battery information	• Physical labeling requirement • Digital identifier • Universal diagnostic system

Support repurposing, reuse, and recycling industry development

- Recycling incentive packages
- DTSC permit timeline
- Expand eligibility for battery storage systems

Safe and efficient reverse logistics

- Support enforcement of unlicensed dismantling laws
- Develop training materials
- Support transportation research
-
- Develop strategic collection and sorting infrastructure
- Universal waste regulations
- Require pre-approval to bid on EVs at auctions

What policies weren't recommended?

Policies that would add requirements and standards to recycling processes or battery manufacturing did not receive support from a majority of the group members and were not included in the final recommendations to the state. These were discussed unfavorably by a majority of the members stating the potential for stifling the growth of a young industry. This is despite the sustainability benefits many of the policies would provide.

The policies include requiring batteries to be made with recycled content and designed with recycling and repurposing in mind. Recycling requirements discussed included minimum material recovery rates, third-party verification of the process efficiency and environmental impact, and the reporting of EV batteries retiring, recycled, and materials recovered. These are all policies that have been proposed by the European Commission and are expected to become law in the European Union.

These policies were all supported by the public interest organizations, along with many of the waste industry representatives. They were not supported by the automotive and battery industry. The combination of opposition from the automotive battery industry (43% of the votes) and some of the waste industry (36% of the votes) resulted in none of the circularity and quality recycling policies reaching over 50% support and being recommended.

Policies with less than majority support

Category

Circular economy and quality recycling

- Recycled content standards
- Minimum material recovery targets
- Third-party verification of recycling
- Required design for reuse and recycling
- Reporting system for EV batteries retired from use, recycling, and recovery rates

So, what's next?

California legislature, it's your move.

The report has been delivered to the legislature to advise them as to what policies will lead California to 100% recycling of EV batteries. They will be back in session in January of 2023, and it is still unknown what the next steps will be. UCS hopes to see policies passed in California which not only requires the recycling of these batteries, but also increases the circularity of materials and battery sustainability.

Posted in: [Transportation](#)

Tags: [California](#), [EV batteries](#), [lithium ion batteries](#), [policy](#), [recycling](#)

What Can We Learn From the EU Battery Law?

February 3, 2023 | 8:00 am



Jessica Dunn
Senior Analyst

Last December, the European Union (EU) [agreed](#) on a [comprehensive battery policy](#) that aims to make electric vehicles (EVs) more

sustainable. Included in the regulation are requirements for mineral sourcing, life cycle emissions, information sharing, and recycling. These regulations set a precedent for battery policy; an area where the US needs to do more.

The US doesn't need to reinvent the wheel here—many of these policies can and should be implemented domestically.

Why does the EU need new battery regulations?

The EU is transitioning away from gasoline vehicles because of their significant contribution to climate change and adverse health impacts— [transitioning to EVs](#) offers an attractive solution. EVs have no tailpipe emissions and their life cycle impacts are much less than the gasoline alternative, not even taking into account the potential for batteries to become more sustainable. The mining for minerals used in batteries is often associated with negative human rights and environmental impacts. However, innovative approaches can reduce those harms, including the creation of a circular economy through reuse and recycling.

Supporting a circular economy

This may seem counter-intuitive, but let's start by talking about regulations that touch retired EV batteries.

When a battery cannot be used in an EV, it should be [repurposed](#) for a different application, such as [stationary storage](#), and then eventually be recycled. The materials can then be recovered and used in the manufacturing of next generation EVs. This process is referred to as the [circular economy](#) because materials are being returned to use, which lessens environmental impacts and reduces waste. *Essentially, it is decoupling economic activity from resource extraction.*

The EU battery law seeks to increase circularity through a plethora of measures that the US can replicate. These measures include requiring automotive companies to recycle the batteries when they reach the end of their life, recover a minimum amount of the materials through

recycling, and using these recovered minerals in the manufacturing of new batteries. The law also requires the increased sharing of information about the battery type and use, making repurposing and recycling more efficient.

Let's take a closer look...

Extended Producer responsibility and reporting: This regulation requires that automotive companies ensure retired batteries are collected and then reused, repurposed, or recycled. The companies are required to report the level of recycling, which provides a route to monitor compliance. The regulation also encourages the extended use of the battery through repurposing for second-life applications. They consider the repurposed battery to be a new product and therefore the repurposer is now responsible for ensuring it is eventually recycled.

Recycling recovery rates: Recovery rates specify that amount of material recovered from the recycling process. The regulation requires an overall recycling recovery rate of 65% by 2025 and 70% by 2030. Higher recovery rates are specified for the more valuable materials: in 2025 the recovery rate of cobalt, nickel, and copper must be 90% and lithium 50%, increasing to 95% and 80% respectively in 2030.

Recycled content standards: Once materials are recovered, they can be [used to manufacture new batteries](#). The regulation proposes recycled content standards, a measure requiring a certain percentage of recycled materials to be used in the manufacturing of new batteries. These standards start at 16% for cobalt, 6% for lithium, and 6% for nickel in 2030 and then increase to 26%, 12%, and 15% respectively in 2035.

Sharing of information: Information such as battery chemistry, mineral sourcing, and [battery health](#) are not currently provided by the automotive companies. This lack of information results in several end-of-life complications: 1) it takes extensive testing to know if the battery is suitable for repurposing, and 2) the battery value is difficult to assess because the health and the chemistry are unknown.

The regulation proposes the use of labelling to clarify battery characteristics as well as the use of a [battery passport](#), which will provide detailed information on the material supply chain, the use of the battery, and the [state of health](#). This is potentially a revolutionary technology that can increase material sourcing transparency, expedite end of life processes, and help track the life of batteries.

Material sourcing and manufacturing requirements

The impacts upstream from the EVs represent the majority of impacts, and over the next several decades there will need to be materials mined to supplement the recycled content. The EU law has laid out steps to decrease those impacts, including supply chain due diligence and carbon footprint limits.

Supply chain due diligence: EVs are a more sustainable alternative to gasoline vehicles, but we must continue to address the impacts associated with sourcing battery materials. The regulation seeks to reduce sourcing impacts through implementing a framework based on several principles, including the Ten Principles of the United Nations Global Compact and the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas.

Essentially, the companies will be required to identify and address risks in the battery supply chain that infringe on the protection of human rights, including human health, protection of children, and gender equality. While the rules are stricter than those in the US, [Amnesty International](#) recently stated that the policies only provide safeguards against harm and don't provide access to remedies such as compensation if their rights are infringed on.

Battery carbon footprint: The life cycle carbon footprint of the battery is required to be included on the label of the battery, easily communicating this information to consumers. In addition, an assessment will be completed to determine maximum carbon thresholds for EV batteries.

Europe is paving the way- will the United States follow?

The US has not enacted any of the policies that were listed above. Instead, they have taken a different approach of [dispersing federal funds](#) for battery recycling and repurposing research, development, and demonstration projects. Battery repurposing and recycling in the US is reliant on these processes being profitable and does not provide policy safeguards that ensures if the economics don't work out, the battery is still eventually recycled. Ideally, the federal government would follow the EU's lead and enact similar policies to ensure optimal resource recovery and a sustainable and circular battery economy.

Currently, the US does have the potential to increase the availability of information to help circularity through the implementation of current law. The Inflation Reduction Act (IRA) sets requirements for sourcing EV battery minerals in the clean vehicle tax credit. There will need to be tracking of these batteries to ensure they meet the requirements. This presents an opportunity to draw on the example of the battery passport, which can help tracking and make repurposing and recycling more efficient. [Ford](#) is piloting a battery monitoring system as we speak, and policy can help speed up this adoption process.

California, the leader of US EV adoption, is also leading the US in progress towards EV battery recycling requirements. A state appointed advisory group released [a report](#) last year with policy recommendations to increase recycling. While their recommendations represent a leap forward beyond the business as usual by requiring recycling and increased information sharing, the EU policy goes much further by including the full battery life cycle and requirements such as recycled content standards and material recovery requirements.

As the California legislative session kicks off, we look forward to seeing how EV battery recycling regulation develops. Stay tuned for opportunities to support California and US battery recycling policies.

Posted in: [Transportation](#)

Tags: [Battery Electric Vehicle](#), [climate change](#), [lithium ion batteries](#), [recycling](#)

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About the author

[MORE FROM JESSICA](#)

Jessica Dunn is a senior analyst in the Clean Transportation Program, specializing in lithium-ion battery sustainability. She conducts research on material circularity and reducing battery impacts through repurposing and recycling.

Guiding Principles for EV Battery Recycling Policy

February 27, 2023 | 8:00 am



Jessica Dunn
Senior Analyst

Electrifying our transportation system is essential for mitigating emissions that cause climate change and adverse health impacts. This electrification will require a lot more batteries and therefore a lot more

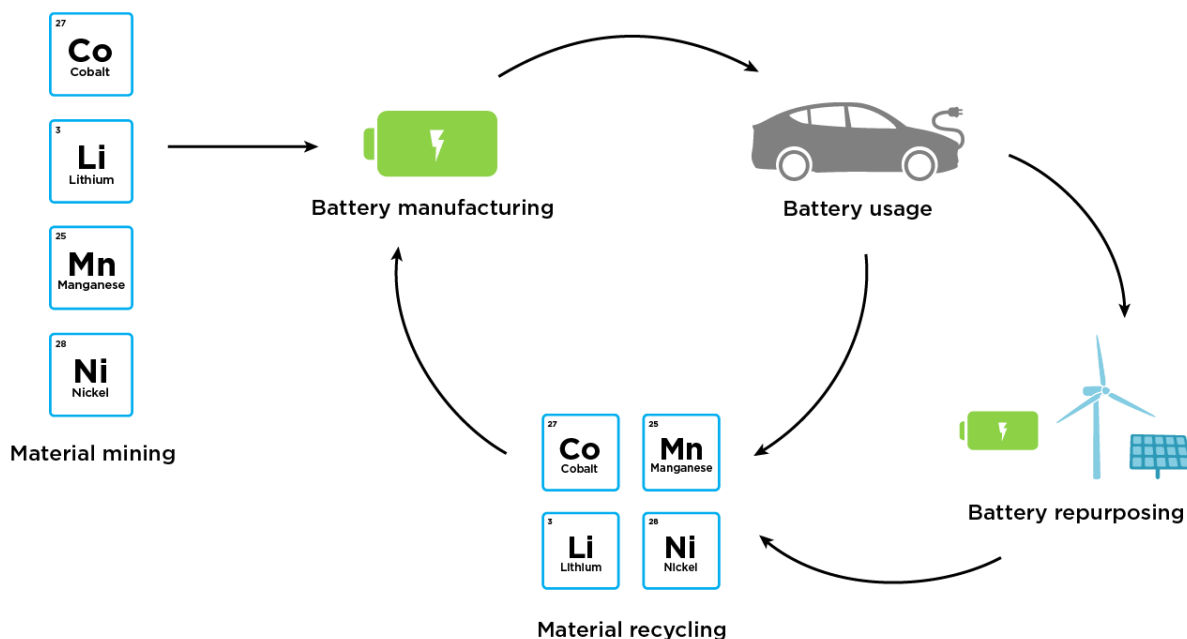
minerals. Recovering these materials from retired electric vehicle (EV) batteries is an alternative source to mining. Essentially, the materials recovered through battery recycling can replace future material supply that would otherwise need to be extracted from the earth to meet demand.

[Estimates](#) show that in 2050, the United States can meet about half of EV demand for cobalt and nickel and a quarter of lithium with minerals recovered through recycling. While EVs already result in [less](#) greenhouse gas emissions than the gasoline alternative, using these recycled materials [substantially lowers](#) impacts associated with material sourcing.

Prior to recycling, the battery retired from use in an EV can be used in a [second-life application](#). This means it is either reused in another vehicle or it is repurposed for use in a stationary storage application. Eventually, the battery will reach its end of life and should be [recycled](#), recovering minerals to then go back into the battery manufacturing stream.

The circular process starts at manufacturing, flows to the first use in an EV, is repurposed for a second life, recycled, and then eventually the minerals are back to manufacturing. This is referred to as material circularity or the [circular economy](#).

EV Battery Material Circularity



Battery policy agreed upon in the [European Union](#) implements circular economy principles and is the most ambitious battery policy to date. It has the potential to increase the recycling of batteries and the use of recovered materials through extended producer responsibility and recycling requirements. In the US, California is also exploring recycling and material circularity policy. In 2022, a [report](#) was released by the [California Electric Vehicle Battery Recycling Advisory Group](#) which outlines policies the group believes the California legislature should implement.

Policies discussed and proposed by these groups have the potential to increase the reuse, repurposing, and recycling of batteries, as well as mitigate impacts associated with end-of-life processes and increase battery sustainability. As policies develop, we at the Union of Concerned Scientists have outlined the following high-level principles that we will use to guide our policy positions.

Guiding principles

1. Increased battery recycling and material circularity is necessary for a sustainable battery industry.
2. The producer (in most cases, the vehicle manufacturer) should be responsible for ensuring EV batteries are reused, repurposed, and eventually recycled.
3. The battery recycling process should minimize environmental impacts and have a high rate of material recovery, especially for lithium, nickel, and cobalt.
4. Prior to recycling, the battery should be reused, refurbished and/or repurposed, if it is safe and has remaining capacity.
5. The battery end-of-life should be considered during the design of the EV.
6. Information about the battery's health over time should be accessible when the battery is in the vehicle and after its removal.
7. Government funding should continue to support research and development of battery repurposing, reuse, and recycling.

Let's dive into these principles a bit further

Increased battery recycling and material circularity is necessary for a sustainable battery industry.

Recycling EVs already on the road is the most sustainable way to source materials. Embedded in these batteries is a highly concentrated amount of minerals that can be recovered through recycling. Newer recycling [processes](#) report recovery rates of 95% and low pollution impacts. This is a substantially better alternative than incineration-based techniques which do not currently recover any of the lithium and do emit greenhouse gases and particulate matter.

Once recovered, these minerals can be used to manufacture new batteries, therefore reducing the need for new mining. Overall, the decreased mining can make EVs more sustainable and lessen the risk of mishandling through inadequate storage or landfilling.

The producer (in most cases, the vehicle manufacturer) should be responsible for ensuring EV batteries are reused, repurposed, and eventually recycled.

Currently, the United States does not require EV battery recycling. While recycling is occurring, there is the potential for market dynamics to not catch all retiring batteries, therefore leading to improper disposal. Some newer batteries aren't using cobalt and nickel, which are traditionally the highest value minerals in EVs. This trend is beneficial because it results in lower cost and more environmentally friendly EVs. But on the flip side, the recycling of batteries without these minerals isn't currently profitable, and therefore may not be recycled if there isn't regulation requiring it.

One potential policy solution is to define a central party responsible, such as producers, for ensuring batteries are recycled. *Defining responsibility can increase the recycling rate and incentivize planning and efficiency.*

The automotive manufacturers are best suited for this position, following the typical policy structure called Extended Producer Responsibility (EPR). By centralizing responsibility to the automotive manufacturer, it not only ensures the battery is recycled, but also incentivizes the producer to design the battery and EV in a way that makes recycling easier and cheaper.

This has been implemented for EV batteries in the European Union and was proposed by the California Advisory Group (the report uses the term 'producer take-back'). A type of extended producer responsibility is used for ensuring the recycling of several products in [California](#), including mattresses, paint, and carpet.

The battery recycling process should result in low environmental impacts and have a high rate of material recovery, especially for lithium, nickel, and cobalt.

Mineral recovery through recycling old batteries is significantly cleaner than mining new materials, and it is important that policies maximize the environmental benefits of recycling. This can be done through required material recovery rates and environmental impact reporting. Technologies are advancing and several new recycling companies state a [95% material recovery rate](#). This best available

technology should be used, and the use of incineration-based techniques that do not recover lithium should not be allowed.

Prior to recycling, the battery should ideally be reused, refurbished and/or repurposed, if it is safe and has remaining capacity.

Eventually, all batteries should be recycled. But prior, many batteries can be used in the environmentally advantageous second-life application such as reuse, refurbishing, and repurposing. Reuse and refurbishing refer to reusing batteries in the same application, but in a different car. Repurposing refers to using the battery in a different application, such as for stationary storage to support renewable energy generation. Read [this](#) excellent blog if you would like to learn more.

The battery end-of-life should be considered during the design of the EV and the battery.

When an EV is retired, the battery is removed from the vehicle and then typically further disassembled. If the disassembly is planned for during the design of the EV and the battery, the process can become safer and more efficient. [Examples](#) of potential deconstruction process improvements through EV and battery design includes the use of binders instead of adhesives and standardization among pack design. Disassembly is currently a manual process, but if batteries are standardized and built to be taken apart, smart robots could instead do this job.

If extended producer responsibility is established, design for disassembly and recycling is naturally incentivized.

Information about the battery's health over time should be accessible when the battery is in the vehicle and after its removal.

The [battery health](#) refers to the capacity and efficiency of the battery, something that slowly degrades over time and with use. This indicator is typically represented as a percentage and communicates the battery's percent maximum available capacity in comparison to when the battery was new. It is important for EV owners to know the health

of their battery, an indicator that is required starting in 2026 for [EVs in California](#).

It is also important for battery health to be accessible once the battery is removed from the car. The battery health is a key determinant in deciding if the battery should be reused, repurposed, or sent directly to recycling. If the battery is in good health (i.e. relatively high capacity and efficiency), it should be reused or repurposed for a second-life prior to recycling.

Currently, if there is no visual damage, battery repurposers test the health by monitoring it through a complete charge and discharge or a specially designed testing process. This is expensive and time-consuming, but if this information was provided without extensive testing, repurposing can be expedited, and costs reduced.

Government funding should continue to support research and development of repurposing, reuse, and recycling.

As we transition away from the gasoline vehicle to the more environmentally friendly EV, battery recycling and material circularity should be priority. As discussed in a [prior blog](#), there have been funds dedicated towards recycling research, development, and demonstration. While this funding is essential to developing a more sustainable battery industry, we also need policy that requires and ensures a circular battery economy.

What's next for battery recycling policy

At UCS, we want to see that all EV batteries are safely recycled and the materials recovered are used in the manufacturing of next generation batteries. These materials are an essential part of meeting upcoming demand and decreasing the need for mining.

US policy should follow the example of the European Union by implementing extended producer responsibility, requiring high material recovery rates, and increasing access to battery information. Stay tuned for more blogs that dive into these principles.

Posted in: [Transportation](#)

Tags: [Battery Electric Vehicle](#), [electric vehicles](#), [Lithium-ion batteries](#), [recycling](#), [Recycling Clean Energy Technologies](#)

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About the author

[MORE FROM JESSICA](#)

Jessica Dunn is a senior analyst in the Clean Transportation Program, specializing in lithium-ion battery sustainability. She conducts research on material circularity and reducing battery impacts through repurposing and recycling.

Why Do We Need EV Battery Recycling Policy?

March 29, 2023 | 9:08 am



Jessica Dunn
Senior Analyst

Our petroleum-based transportation system has led to [health](#) and [climate impacts](#) felt throughout the world. Electrifying transportation is a valuable tool we can use to [reduce](#) those impacts.

This transition will require an [increase of minerals](#) used in batteries that power our electric vehicles (EVs), trucks, and buses.

When these electric transportation modes retire, the batteries' usefulness continues. Even with diminished capacity, they can be reused, refurbished, or [repurposed](#) and then eventually [recycled](#). The materials recovered from recycling can be used to manufacture new batteries, therefore reducing the amount of newly mined materials necessary to meet upcoming mineral demand.

The EV battery recycling business is just now kicking off, and because of the high value materials in lithium-ion batteries, the economics of this early industry look good. Batteries are being recycled, which has led some to make the case that there is no need for a strict recycling policy because the market will take care of itself. However, the positive economics of battery recycling may not last forever, nor will there be a nickel (get it?) to be made from every EV battery.

Recycling may not always be profitable for lithium-ion batteries that don't contain cobalt and nickel, batteries that are damaged, or for small volumes of batteries located in remote locations. Considering there [is no recycling requirement](#) for retired EV batteries in the US, when the cost of recycling or repurposing a battery is greater than the profit generated, there is risk that the batteries will be landfilled or mishandled.

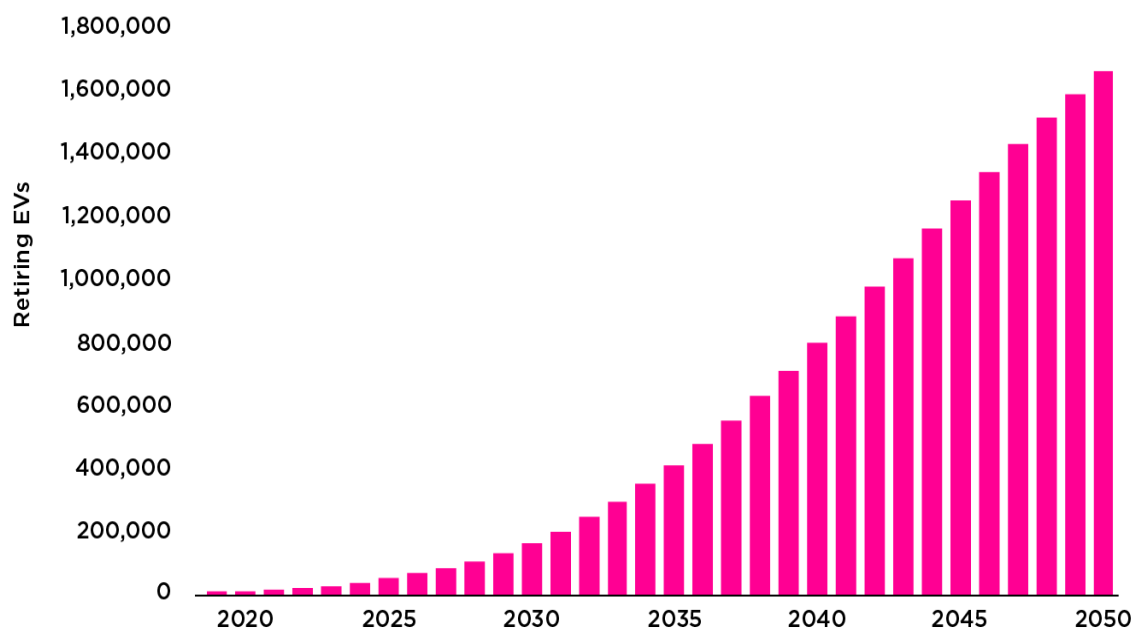
To avoid this very real possibility, we need an [extended producer responsibility](#) recycling requirement. This means being clear about who is on the hook for unprofitable or otherwise unwanted EV batteries. The California legislature is beginning to take on EV battery recycling with Senate Bill 615 which is currently in initial draft form. So, we've decided now would be a good time to explain the problem and the need for a fool-proof solution.

While EVs retiring today are a trickle, this will increase exponentially

The number of batteries retiring today is relatively small in comparison to the number of batteries that will be retiring in the future. This is because EVs have only been a small fraction of auto sales over the last decade. As California transitions to [100% zero emission vehicle sales](#) by 2035, there will be more EVs on the road and batteries eventually ready for recycling.

As the number of retiring batteries increases there is the potential for more batteries to slip through the cracks and not be recycled. An extended producer responsibility can help ensure high recycling rates with the safe and high recovery of materials.

Forecasted EVs Retiring in California



Union of
Concerned Scientists

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Forecasted retirement of EVs sold in California. This calculation is based off the EV sales for California to meet the [Zero Emission Vehicle requirement](#) component of the Advanced Clean Cars II regulation. The survival rates and vehicle sales are based off the California Air Resources Board's [Emission FACtor \(EMFAC\) model](#).

Yes, EV batteries can be recycled

Batteries can be [recycled](#) and there are companies doing so in North America. One US based recycling company has reported that they will take all batteries, even if they are not profitable to recycle. This is part of their [research](#) to identify where batteries are retiring and design efficient collection routes.

Once there is a larger availability of batteries from retiring EVs, recyclers can be a bit pickier as to the batteries they collect. They will likely make the strategic decision to choose those with positive [economics](#), like the batteries that contain cobalt and nickel. Unfortunately, batteries like lithium-ion-phosphate (LFP) that don't contain these two valuable materials currently represent a cost to recycle. Since LFP is only a fraction of retiring supply, it doesn't seem to be a problem yet, but their market share is increasing. As more EVs retire, and as technology changes, recycling companies will likely prioritize batteries of higher material value, better health, and a shorter distance to travel.

Since it can't be guaranteed that recycling all EV batteries will be profitable, it is essential that we ensure a future where even these get recycled and handled safely to avoid improper disposal or them wasting away in landfills.

Instances where there is a disincentive to recycle

Scenario 1: Higher than average cost to collect and transport.

The [costs](#) associated with recycling includes the collection and transportation of the battery (about 29%), the dismantling and disassembly (about 37%), and then the recycling process (about 34%). The [collection and transportation costs](#) vary based on whether the battery is damaged, the distance to a recycling facility, and the volume of batteries shipped.

Damaged batteries have an increased risk of fire and as a result require [extra precautions](#) to ship. This includes additional packaging that must be custom made and comply with the United Nations standards.

Shipping costs per battery also increase with longer distances to travel and when only a few batteries need to be transported. This typically occurs when they are located in remote areas and there aren't enough to fill a truck. In this scenario, the truck with the special [Class 9 hazardous permit](#) is transporting only a couple batteries, therefore operating at partial capacity.

These shipping costs can be decreased with an efficiently designed collection network that optimizes collection points and the infrastructure already in place, such as the currently operating dismantlers and dealerships. Manufacturers are in the prime position to do this centralized planning to ensure that operations are in place for all batteries to be recycled and reap benefits from economies of scale.

Scenario 2: The LFP lithium-ion battery has low revenue from material recovery.

Revenue from selling the minerals that can be recovered from the battery make up the profit from recycling. Batteries that are currently retiring have high amounts of cobalt and nickel, two very valuable minerals. These minerals have been instrumental in EVs success, allowing batteries to be smaller while enabling EVs to go further. There are some alternatives, including [lithium-iron phosphate \(LFP\)](#), that do not contain either of these minerals. LFP hasn't historically been used in EVs sold in the US because the batteries have to be bigger than the nickel and cobalt alternatives to provide the same amount of energy. This is changing as technology develops and EVs become more prevalent.

[Tesla](#) has begun producing a lower range and less expensive EV that uses an LFP battery. Ford, Rivian, and Volkswagen also have [plans for using LFP](#). Since these batteries contain lower value materials, they are also less valuable to recycle. [My research](#) and [others](#) evaluating recycling economics finds that recycling LFP is not currently profitable, therefore creating a disincentive to eventual recycling that may lead to low recovery rates.

Manufacturers can reduce the costs associated with recycling. Extended producer responsibility would incentivize designing these batteries to be more safely and efficiently disassembled which would result in decreased costs of recycling. As mentioned above, the dismantling and disassembling of the battery is estimated to represent about 37% of recycling costs. This is a substantial portion that varies by manufacturer and model because it is based on the time it takes for people to complete the process by hand. The process is lengthy because the battery is not designed to be disassembled and due to lack of standardization, the batteries cannot be taken apart by robotics.

Decreasing the cost of recycling through designing for disassembly has the potential to drive the recycling cost of LFP batteries down, which contain a valuable source of lithium. [Recycling technologies in development](#) could also lead to profitable recycling of LFP, therefore representing another potential area of investment for manufacturers that would be incentivized to make LFP recycling profitable.

All EV batteries need to be recycled

A strong recycling policy is essential to ensure that all EV batteries are safely recycled so that the materials can be recovered. If recycling requirements are not enacted, there is the possibility of batteries not being recycled if it is not profitable to do so. This could be either due to the batteries being damaged, in a remote locations, or of lower mineral value.

In addition, if the responsibility of recycling is placed on automotive dismantlers, there is the possibility that these batteries with a disincentive to recycle are pushed into the unlicensed and unregulated dismantling market. This market processes approximately [30% of retiring cars](#) in the US and presents a large environmental and safety risk.

We suggest that an extended producer responsibility program with a recycling requirement is enacted to ensure all batteries are recycled and to drive recycling costs down. This is essential for reducing the amount of mining needed to electrify our transportation system over

the next several decades. This policy is an important aspect in meeting our long-term goals of creating a low impact and circular transportation system.

Posted in: [Transportation](#)

Tags: [electric vehicles](#), [Lithium-ion batteries](#), [recycling](#)

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About the author

[MORE FROM JESSICA](#)

Jessica Dunn is a senior analyst in the Clean Transportation Program, specializing in lithium-ion battery sustainability. She conducts research on material circularity and reducing battery impacts through repurposing and recycling.

Why New DOE Battery Recycling and Repurposing Investments Are Crucial to The Future of EVs

November 21, 2022 | 9:39 am



Jessica Dunn
Senior Analyst

It's been one year since passage of the Bipartisan Infrastructure Law (BIL), which included provisions to further clean transportation. Importantly, the BIL invests in electric vehicle (EV) battery recycling and repurposing—important strategies for increasing the sustainability of EVs.

The Department of Energy recently announced [10 recycling and repurposing projects](#) that will receive a total of \$73.9 million in funding. These projects could be key contributors to the technological innovation and scale up necessary to increase domestic recycling and make second-life stationary storage more accessible.

Currently, transportation is the largest contributor to [climate-changing emissions](#). EVs can significantly [reduce](#) the sector's emissions and set us on a path to reach our climate goals. While EVs deliver major climate emission benefits compared to gasoline vehicles, the recycling and reuse of EV batteries will help ensure the transition to EVs is sustainable over the long term.

Before recycling, batteries in good condition can be repurposed into a [second-life application](#) such as stationary storage. Second-life storage extends the lifespan of EV batteries while also helping decarbonization efforts—[stationary storage](#) is becoming more necessary as more of our electricity comes from renewable sources and as climate impacts threaten grid reliability. For example, storage is used to support solar photovoltaic systems by charging mid-day when the sun is strong and then discharging in the evening when energy demand peaks. In addition, California has begun exploring the option of using stationary storage as a backup resource when electricity is turned off [to prevent wildfires](#).

When batteries reach the end of their life, they can all be [recycled](#). The materials recovered can be used in the manufacturing of new batteries, resulting in large sustainability gains. The recycled materials replace the need for newly mined materials, therefore [lessening the amount](#) of mining necessary for the clean energy transition and creating a domestic supply.

These nascent industries are expanding rapidly and the Bipartisan Infrastructure Law investments are carefully aimed at addressing key challenges in repurposing, recycling, and the uptake of EVs.

What second-life projects were funded?

The Bipartisan Infrastructure Law funds went to five different second-life demonstration projects. The parties involved in these projects are wide ranging, including Universities, National labs, Utilities, auto manufacturers, well established companies, and startups.

Second-life demonstration projects include providing access to energy storage in underserved communities and EV charging in rural areas, as well as tech development that increases access to information and control over battery operations.

One project is aimed specifically at using these repurposed batteries to increase the accessibility of EV [charging in rural areas](#). The stationary storage will be used as a charging station to provide more options for drivers to charge and provide relief from increased electricity demand on the grid. The effort will provide EV charging infrastructure in a multistate region (including Tennessee, Ohio, Virginia, Kentucky, West Virginia, Kansas, and Texas) and aide in the electrification of underserved rural communities.

Several of these projects are focused on technological improvements that will increase the efficiency and safety of second-life storage. Improvements begin with determining the [battery health](#) — this is a necessary estimation used for assessing if the battery is suitable for a second-life application. This estimation process is critical but lengthy. A second-life company received funding for technology that can drastically speed up the process, estimating the battery's health in two minutes.

After the batteries have been tested and diagnosed as safe for repurposing, they are combined to make a larger storage system. This storage system is a mix of batteries with varying levels of capacity and the performance is restrained by the lowest performing cell. The

charging and discharging of the cells are typically controlled in unison, restricting the capability of batteries and degrading them at a higher than preferable rate. Technology that enables more refined control of battery operations and knowledge of cell health was proposed in three of the five fund recipients. These innovations have the potential to increase the efficiency, lifespan, and safety of second-life storage.

What about battery recycling projects?

The other half of funded projects are focused on the development of recycling processes. Recycled materials have the potential to greatly [decrease](#) environmental and social impacts associated with batteries. Through their recycling and recovery, the need for newly mined materials can be reduced and the materials can continue to be used within the economy.

One recycling technique, called [hydrometallurgical processing](#), has made great strides demonstrating high recovery rates of critical materials (think cobalt, nickel, manganese, and lithium) that can be used to manufacture new batteries. The technology is already operating at industrial scale and ready for expanded capacity. This funding will be used to continue improving this recycling process and build facilities in Nevada and Ohio.

The further development of a new recycling process, typically called [direct cathode recovery](#), was also funded. This process recovers the battery materials in a form that is further along the manufacturing process. Essentially, instead of recovering the constituent materials like hydrometallurgical recycling does, direct recycling recovers these materials in their combined and processed form. The material recovered from using the direct cathode recovery process can more readily be reused, reducing the number of energy intensive steps in the manufacturing process.

A step in the right direction

This historic investment will greatly increase the repurposing and recycling innovation and infrastructure in the United States. It's a

necessary step in the direction towards a more circular, low impact, and domestic electric vehicle economy.

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Tags: [climate change](#), [electric vehicles](#), [EV batteries](#)

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