Office of Industry and Competitiveness Analysis
Working Paper ICA-23-097

A Preliminary Examination of the Trade Competitiveness and Climate Objectives in the Inflation Reduction Act of 2022

February 2023

David Coffin
Advanced Technology and Machinery Division
david.coffin@usitc.gov

Samantha DeCarlo
Chemicals and Textiles Division
samantha.decarlo@usitc.gov

Dixie Downing
Advanced Technology and Machinery Division
dixie.downing@usitc.gov

Samuel Goodman
Chemicals and Textiles Division
samuel.goodman@usitc.gov

Fernando Gracia
Advanced Technology and Machinery Division
fernando.gracia@usitc.gov

Robert Ireland
Natural Resources and Energy Division
robert.ireland@usitc.gov

Steven LeGrand
Agriculture and Fisheries Division
steven.legrand@usitc.gov

Nathan Lotze
Advanced Technology and Machinery Division
Nathan.lotze@usitc.gov

Mitchell Semanik
Advanced Technology and Machinery Division
mitchell.semanik@usitc.gov

Brennan Taylor
Advanced Technology and Machinery Division
brennan.taylor@usitc.gov

Office of Industry and Competitiveness Analysis
U.S. International Trade Commission

Introduction

The Inflation Reduction Act of 2022 includes the single largest climate investment in U.S. history at $369 billion.[1] The act was signed into law by President Biden on August 16, 2022.[2] The law's Energy Security and Climate Change Investments aim to increase U.S. energy security and reduce global greenhouse gas (GHG) emissions. Combined with climate investments in Congress's FY2022 Budget Reconciliation bill, the Inflation Reduction Act of 2022 (IRA, hereafter) could lead to an estimated 40 percent reduction in U.S. emissions by 2030 according to the U.S. Senate.[3] Historically, the U.S. is the largest producer of GHG emissions – accounting for 22 percent of historic GHG emissions.[4] Domestic GHG emissions grew by 6.2 percent in 2021 compared to 2020.[5]

This working paper, *A Preliminary Examination of the Trade Competitiveness and Climate Objectives of the Implications of the Inflation Reduction Act of 2022*, is split up into four chapters and a conclusion tying them together:

1. Chapter 1 discusses the industries impacted by the IRA's clean vehicle provisions, and it provides key details and analysis on source markets for critical minerals needed for electric vehicle (EV) batteries.
2. Chapter 2 discusses tax credits for domestic manufacturing of wind turbines and solar panels, tax credits for nuclear energy production, and investments into energy research at the U.S. Department of Energy's National Labs which specialize in hydrogen and nuclear energy research.
3. Chapter 3 discusses the IRA's provisions to improve the air and water quality in urban and rural disadvantaged communities. It includes efforts to mitigate air pollution at ports including carbon capture, utilization and storage, automated ports, and sustainable aviation fuel and investments into agricultural research and biofuels.
4. Chapter 4 discusses the direct incentives for consumers with the goal of encouraging more energy efficient decisions including tax credits, consumer home energy rebate programs, and a grant program to make affordable housing more energy efficient.

[1] Public Law 117-169. Congressional Research Service. "Inflation Reduction Act of 2022: U.S. Environmental Protection Agency and Selected Other Environmental Provisions," August 2022.
[2] Donald, Judd and Vazquez, Maegan, "Biden signs Inflation Reduction Act into law," August 2022.
[3] U.S. Senate, "Summary of the Energy Security and Climate Change Investments in the Inflation Reduction Act of 2022," August 2022.
[4] The World Economic Forum estimates that the world must invest $5.7 trillion annually (up to 2050) in green infrastructure and other adaption and mitigation efforts to avoid the worst effects of climate change. World Economic Forum, "The Green Investment Report: The ways and means to unlock private finance for green growth," 2013. Childs, Frances, Christianson, Anne, et al., "How the Inflation Reduction Act Will Drive Global Climate Action," August 2022.
[5] Childs, Frances, Christianson, Anne, et al., "How the Inflation Reduction Act Will Drive Global Climate Action," August 2022.

Chapter 1: Critical Minerals and Battery Components for Electric Vehicles

David Coffin, Samantha DeCarlo, Dixie Downing, and Samuel Goodman

The Inflation Reduction Act of 2022 prioritizes the U.S. clean vehicles and critical minerals industries. The law includes $3 billion for Advanced Technology Vehicle Manufacturing loans and $2 billion for grants as well as consumer tax credits for new and used electric vehicles, electrode active materials, battery cell manufacturers, and module producers.[6] Access to critical minerals is a major factor in obtaining these tax credits, grants, and loans. Chapter 1 focuses on regulations and incentives for EV suppliers related to U.S. production of automotives and parts as well as insights into the landscape of the U.S. production of critical minerals.

EV Supply Chain Incentives in the Inflation Reduction Act

The Inflation Reduction Act has incentives that affect a number of links in the EV Value Chain, including manufacturing grants, consumer tax credits (for new and used vehicles), battery production incentives, and critical minerals mining and processing incentives. These incentives will likely boost both supply (lowering production costs) and demand (lowering consumer prices) for electric vehicles in the United States.

The IRA provides $3 billion for Advanced Technology Vehicle Manufacturing loans and $2 billion for grants.[7] This is the continuation of a program that was started in 2009 to provide loans and grants for manufacturers to convert plants from producing internal combustion engine (ICE) vehicles to electric vehicles (EVs). These grants will support vehicle manufacturers as they build new EV plants or transition ICE assembly plants to EV plants.[8]

There are two consumer tax credits for new EV purchases in the Inflation Reduction Act.[9] Each of the two tax credits are $3,750 per vehicle, totaling $7,500:

1. Critical mineral requirement- an increasing percentage of the value of the critical minerals in the battery must be either extracted or processed in the United States, a country which the United

[6] Public Law 117-169, §§ 50142, 13401.
[7] Public Law 117-169, §§ 50142 and 50143.
[8] DOE, "Advanced Technology Vehicles Manufacturing Loan Program," (accessed October 7, 2022).
[9] "Clean Vehicle Credit" of the Inflation Reduction Act establishes the two requirements for the two credits for consumers. Public Law 117-169, § 13401. Guidance from the U.S. Treasury on how many portions of the Clean Vehicle Credit will be interpreted has not yet been published. This process has been the subject of intense lobbying by the automotive industry, and the EU, as many are hoping for increased flexibility in meeting the rules. Williams, "Lawyers and Lobbyists Get Creative," November 28, 2022.

States has a trade agreement or recycled in the United States.[10] Those percentages start at 40 percent before 2024 and increase by 10 percentage points per year until reaching 80 percent for vehicles beginning in 2027. Several dozen critical minerals (including lithium, cobalt, graphite, and other important battery-related minerals) are included in the act's "definition of critical mineral," including all key battery minerals.[11]

2. Battery component requirement- vehicles produced in 2023 must have 50 percent components produced in North America, with that percentage increasing to 100 percent by 2029. Battery components include "electrode active materials", battery cells, and battery modules.[12]

The IRA also provides a $4,000 incentive for the purchase of a used electric vehicle from a dealer of less than $25,000.[13] This incentive is not restricted to EVs produced in North America. This should provide a significant boost to the retail value of used electric vehicles. The used market is generally significantly larger than the new market (40 million used vehicles sold per year vs. 15-17 million new in the United States), but the current stock of used electric vehicles is relatively low. Cumulative U.S. EV sales from 2017 to 2021 totaled less than 1.3 million units.[14] There may also be concern about purchasing used electric vehicles, as lithium-ion batteries tend to lose range as they age, and expensive to replace.[15] This incentive will likely help support used EV prices.

Vehicle manufacturers will have to make significant changes to their manufacturing supply chains to produce vehicles that are eligible for the consumer tax incentives for new EVs. In 2021, eleven electric light vehicle models were produced in North America, but only six used cells that were manufactured in North America (table 1.1). Vehicle manufacturers have announced significant investments in battery manufacturing in North America ($60 billion in 2021 and 2022, up from $22 billion in 2019).[16] However, many EV manufacturers may still need to import cells to meet projected demand through 2030, which is projected to increase rapidly from 5 percent of vehicle sales in 2021 to 21-50 percent in 2030.[17] The critical mineral and component requirements will be even more challenging for North American EV manufacturers, as many of the components and most of the minerals (cobalt, graphite, manganese) are not produced or found in North America.[18] Many believe that few, if any models will be immediately eligible for the rules as the percentages increase.[19]

[10] More information of the U.S.'s supply of critical minerals can be found in the "U.S. Manufacturing and Competitiveness in Critical Minerals" section below. Appendix A includes the full list of critical minerals defined in the IRA. The list includes all of the major minerals in lithium-ion battery production including cobalt, graphite, lithium, manganese and nickel.
[11] Public Law 117-169, § 45X.
[12] Electrode active materials are the components that make up battery cells (e.g., cathode, anode, electrolyte, etc.), which get combined together into battery modules before being combined with battery management systems to form the battery pack for an electric vehicle. Public Law 117-169, § 45X.
[13] Public Law 117-169, § 13402
[14] IEA, "Global EV Data Explorer," Updated September 2022.
[15] Campbell, Peter, "Switch to electric cars held back by costly leasing deals," September 2022.
[16] Bush, "Automakers Invest Billions in North American EV and Battery Manufacturing Facilities," July 2022.
[17] IEA, "Global EV Data Explorer," Updated September 2022.
[18] Bozzella, John, "What If No EVs Qualify for the EV Tax Credit?" August 2022. See Appendix A for all critical minerals. There is mining of lithium in the United States, but not in the quantities needed to support U.S. lithium-ion battery production.
[19] Bozzella, John, "What If No EVs Qualify for the EV Tax Credit?" August 2022.

Table 1.1 EV Assembly and Battery Assembly Location for EVs Produced in North America

Vehicle model	U.S. Sales	EV Assembly Location	Battery Manufacturer (global HQ)	Pack Assembly Location	Cell Manufacturing Location
Tesla Model Y	162,968	United States	Tesla (U.S.)/Panasonic (Japan)	United States	United States
Tesla Model 3	139,503	United States	Tesla (U.S.)/Panasonic (Japan)	United States	United States
Mustang Mach E	27,140	Mexico	LG Chem (Korea)	Mexico	Poland
Chevrolet Bolt EV	22,073	United States	LG Chem (Korea)	United States	United States
Tesla Model S	16,672	United States	Tesla (U.S.)/Panasonic (Japan)	United States	Japan
Nissan LEAF	14,239	United States	Envision-AESC (Japan)	United States	United States
Chevrolet Bolt EUV	2,755	United States	LG Chem (Korea)	United States	United States
Tesla Model X	1,265	United States	Tesla (U.S.)/Panasonic (Japan)	United States	Japan
Rivian R1T	326	United States	Samsung SDI (Korea)	United States	South Korea
Rivian R1S	50	United States	Samsung SDI	United States	South Korea
Hummer Pickup	1	United States	GM (U.S.)/LG Chem (Korea) JV Ultium	United States	United States
Total	386,992				

Source: Author collected information and Ward's Intelligence.

There are several incentives for the manufacture or production of EV batteries or their inputs that will encourage further investment in the EV battery supply chain in the United States. Electrode active materials receive a credit equal to 10 percent of the costs to produce such materials. Battery cell manufacturers receive a credit of $35 per kilowatt hour, module producers receive $10 per kilowatt hour, or if there is no separate cell the module producer receives $45 per kilowatt hour. Assuming an average battery size of 80 kwh, that is roughly $3,600 per EV battery, plus the 10 percent on the production of electrode active materials. Critical mineral producers also receive a credit equal to 10 percent of costs to produce such minerals.[20]Most of these incentives expire in 2032, with the exception of the critical mineral incentive, likely an acknowledgement of the longer time horizon for developing new mines.[21]

U.S. Manufacturing and Competitiveness in Critical Minerals

The IRA or the "act" defines a set of "applicable critical minerals" that impact the ability of a claim to meet the requirements of several credits throughout the Act.[22] Table A.1 in the appendix provides a summary of the 72 materials on this list.[23] These materials run the gamut of metals and chemicals used in advanced manufacturing, ranging from commodity-scale products like aluminum to rare earths and

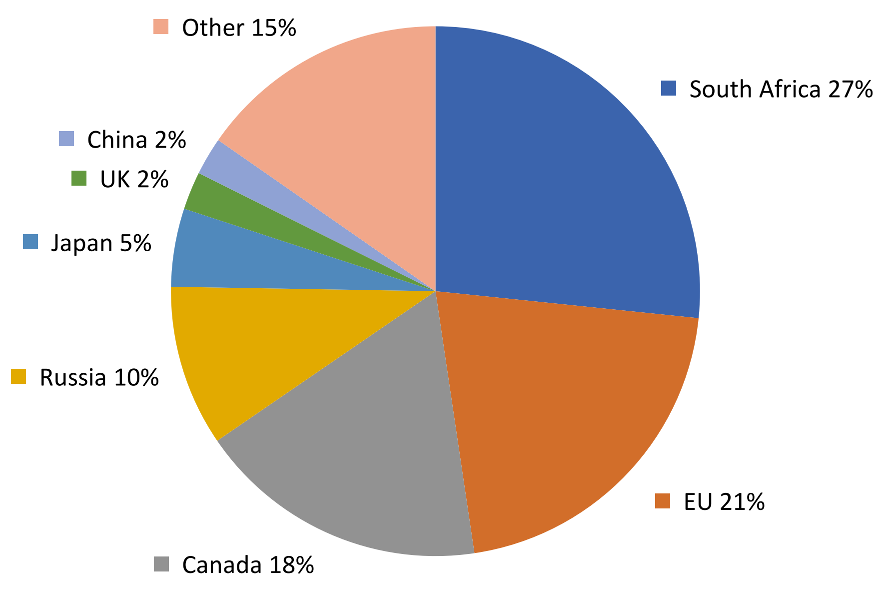
[20] Public Law 117-169, § 13402 amending 45X(b)(1).
[21] Public Law 117-169, § 13402 amending 45X(b)(1).
[22] Public Law 117-169, § 13502 (amending § 45X(c)(6) of the Internal Revenue Code of 1986). See also IRA §§ 13401 and 13501.
[23] See table AX in the appendix for a full list and additional information.

specialty alloys. Many of the requirements for credit in the act are centered on critical minerals extraction locations (i.e., primary production) or processing of said materials, therefore, it is important to understand their current global supply chains.

As of 2021, the majority of critical minerals cited in the act lack U.S. production (see table A.1-Column "U.S. prod"). Over two-thirds (68 percent, 49 out of 72) of the critical minerals have either no primary production or beneficiation in the United States. Building capacity in some of these critical minerals is also hampered because of a lack of proven, economically viable reserves. Metals like manganese and tantalum have no identified deposits that are viable for extraction; while other critical material containing ores exist (e.g., cesium and indium) but the extent of the deposits and mining viability are unknown. Even among those with domestic sources and proven reserves, few U.S. minerals are major components of their global value chains. Beryllium is the one example that breaks this rule, with U.S. material accounting for the majority of product entering global commerce. Others, like rare earth oxides, constitute substantially lower fractions of world output.

The United States largely depends on imports of many of these materials. Sources are concentrated among a handful of countries and global regions (figure 1.1). Each country or region produces a different mix of critical commodities based on their own natural resources and industrial capacity (a breakdown in product is provided in table A.1 in the appendix). In most cases, each industry is highly concentrated, with only a few, or even one, primary supplier to the global market for a given commodity. China, for example, likely provides over 80 percent of global bismuth and three-quarters of rare earths, while South Africa is the primary source of platinum group metals. Advanced manufacturers in the United States are thus currently reliant on many global value chains for access to the materials they need to produce the technologies covered by the IRA.

Figure 1.1 U.S. imports of applicable critical minerals by source, value, 2021



Source: USITC/DOC DataWeb.

Note: EU is the sum of imports from all countries in the European Union. UK is the United Kingdom. Values are aggregated across all applicable products, and variation in source is high across commodities.

Chapter 2: U.S. Manufacturing and Competitiveness in Green Energy

Dixie Downing, Fernando Gracia, and Nathan Lotze

The Inflation Reduction Act of 2022 outlines the positive impacts of clean energy as both a means to mitigate climate change and national security risks. Supply shocks in the fossil-fuel supply chain have led to policymakers rethinking their energy security priorities. The IRA provides tax credits for domestic manufacturing of wind turbines and solar panels, tax credits for nuclear energy production, and investments into energy research at the U.S. Department of Energy's National Labs which specialize in hydrogen and nuclear energy research.

One goal of the IRA's investments into clean energy manufacturing and technologies is to establish less reliance on fossil fuels and greater energy security through lesser impacts from fuel supply shocks caused by foreign conflicts or events.[24] Investments aimed at bolstering U.S. manufacturing of renewable energy could increase U.S. international competitiveness in developing countries making clean energy transitions and adaption plans – creating a first mover advantage for U.S. firms.[25] Chapter 2 dives into incentive programs introduced in the IRA for solar, wind, nuclear, and hydrogen energy while discussing the current landscape of each industry.

Solar power is considered the most plentiful and accessible renewable energy source on the planet. By the end of 2021, the U.S. held 119.7GWdc of total installed solar capacity, and 11 states generated more than 6 percent of their power through solar energy.[26] In 2021, U.S. solar installations included 77.2 GWdc in utility solar, 4.3 GWdc in community solar, 15.3 GWdc in commercial solar, and 23.1 GWdc in residential solar – with more than 255 thousand Americans employed in the solar sector.[27] Investments in the IRA are expected to increase solar installations by 40 percent (or 62 GWdc) in the next five years.[28] The law includes provisions to bolster domestic manufacturing of solar panels and investment tax credits to build facilities focused on manufacturing clean technologies.[29]

Chinese companies lead the solar industry in revenue and shipment capacity (table 2.1).[30] According to a July 2022 report by the International Energy Agency, China has significantly expanded solar panel

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[24] Orvis, Robbie, "Energy Security Benefits of Congressional Climate and Clean Energy Policy," March 2022.
[25] Childs, Christianson, and Colón, "How the Inflation Reduction Act Will Drive Global Climate Action," August 2022.
[26] GWdc means gigawatts direct current; this is the power produced by solar panels themselves. National Renewable Energy Laboratory, "Spring 2022 Solar Industry Update," 2022.
[27] Fischer, Anne, "Solar jobs increased 9% nationwide in 2021," July 2022. Solar Energy Industries Association, "Solar Industry Research Data," accessed September 2022.
[28] Ludt, Billy, "Inflation Reduction Act increases US solar installation projections by 40%," September 8, 2022.
[29] U.S. Senate, "Summary of the Energy Security and Climate Change Investments in the Inflation Reduction Act of 2022," August 2022.
[30] Statista, "Annual revenue of JinkoSolar from financial year 2011 to 2021," 2022. Shaw, Vincent and Hall, Max, "Chinese PV Industry Brief: Soaring profits for Trina and Shuangliang," February 22, 2022. Statista, "Net revenue of Canadian Solar Inc. from financial year 2009 to 2021," 2022. Taiyang News, "LONGi Exited 2021 With 105 GW Wafer Capacity; Shipped 6.44 GW Modules In Q1/2022," April 28, 2022. Rai-Roche, Sean, "LONGi launches new 66-cell PV module for European solar market," September 12, 2022. LONGi Green Energy Technology Co. "LONGi releases its annual report for 2021 and Q1 2022," May 5, 2022. Reuters, "JA Solar Technology Co Ltd," accessed September 2022. Aleina, "Net Profit 8.208 Billion Yuan! Tongwei Discloses Performance 2021 and Q1 2022 Results,"April 26, 2022. Energy Sage, "Top solar panel manufacturers," accessed September 2022.

production in the past 10 years.[31] The same report states that 80 percent of the key manufacturing stages of solar panels reside in China – with key inputs like polysilicon and wafers expected to increase to 95 percent Chinese-production in the coming years based on current manufacturing capacity under construction.[32] Investments in the IRA have the potential to diversify the supply chain by funding domestic manufacturing of solar inputs and decreasing reliance of Chinese solar imports.[33]

Table 2.1 Brief overview of major global solar producers

Producer	Headquarters	2021 revenue (billions)	Major types of solar panels produced	2020 solar module shipment capacity (GW)
LONGi Solar	China	$11.6 (CNY 81.1)	monocrystalline solar panels	14.7 GW
Tongwei Solar	China	$9.1 (CNY 63.7)	crystalline silicon solar cells	12.1 GW
Trina Solar	China	$7.0 (CNY 49.0)	monofacial modules, bifacial modules	9.0 GW
JinkoSolar	China	$6.1 (CNY 42.7)	monocrystalline silicon solar cells	8.7 GW
JA Solar	China	$5.9 (CNY 41.3)	half-cell mono PERC modules	10.8 GW
Canadian Solar	Canada	$5.3 (CAD 7.0)	monofacial modules, bifacial modules	8.3 GW
First Solar	USA	$2.9	thin-film solar panels	5.5 GW

Note: Many of these firms produce multiple types of solar cells and panels. The ones listed are select major products of each firm. Sources: Statista, PV Insights

Wind Energy

The Inflation Reduction Act extends the production tax credit (PTC) for wind projects that commence construction by the end of 2024.[34] Under previous law, the PTC was only available to facilities that began construction before January 1, 2022.[35] Along with this three-year extension, the IRA also modifies the PTC by including prevailing wage and apprenticeship requirements for a wind project to qualify beyond the base credit of 20 percent PTC.[36] Additionally, under the IRA a "bonus credit" amount would be provided to wind projects that meet domestic content requirements related to certain steel, iron,

[31] International Energy Agency, "The world needs more diverse solar panel supply chains to ensure a secure transition to net zero emissions," July 7, 2022.
[32] International Energy Agency, "The world needs more diverse solar panel supply chains to ensure a secure transition to net zero emissions," July 7, 2022.
[33] Lee, Elizabeth, "US Boosting Domestic Solar Industry, Reducing Reliance on China," August 17, 2022.
[34] U.S. Congress, "Inflation Reduction Act of 2022," August 2022. Pp. 242-261.
[35] Under the IRA, the current PTC phaseout still applies to any wind project placed in service before January 1, 2022. U.S. Congress, "Inflation Reduction Act of 2022," August 2022. Pp. 242-243. McGuireWoods, "Inflation Reduction Act Extends and Modifies Tax Credits for Wind Projects," August 24, 2022.
[36] If a wind project does not meet these requirements, the project would still be eligible for the base rate of 20 percent PTC.

and manufactured products used in the facility.[37] The credit amount could also increase by 10 percent if the wind project is located in an energy community.[38]

Box 1 Sustainability and Finance in the U.S.

Initiatives to prioritize investments into climate-friendly solutions have emerged in the United States. The IRA includes $27 billion towards a clean energy technology accelerator to support the deployment of green and emission-reducing technologies – with roughly $7 billion dedicated to projects in disadvantaged communities with the potential to reduce consumer energy costs.a These investments may support the Greenhouse Gas Reduction Fund – administered by the EPA – and provide competitive grants to national and local "green banks."b A study by the California Center for Sustainable Communities at UCLA noted that historically, public incentive programs to reduce GHG emissions and promote energy efficiency have disproportionately impacted wealthier communities.c Since green banks are mission-driven initiatives to invest in clean energy projects for disadvantaged communities, lower income communities may be at the forefront of future investment objectives.e The national bank will aid the projects and public-private partnerships already in the works by local green banks. The New York green bank has invested in community solar projects for residents who may not be able to afford their own rooftop solar panels; the success of these projects has led to more loans from private institutions who were previously hesitant to approve funding.f According to the Coalition for Green Capital, 99.6 percent of green bank loan recipients in the U.S. have repaid their green bank lenders prompting loans for further climate-friendly projects.

Public Law 117-169, § 50141. More information on impacts of the Inflation Reduction Act of 2022 on disadvantaged communities in Part 3 of this working paper series.

Green banks are mission-driven financial institutions that actively seek to invest in technologies to accelerate clean energy projects and the fight against climate change. Since these institutions are mission-driven, they prioritize their mission – such as deploying clean energy, improving resiliency and clean projects in low-income communities, and so on – over profits. Coalition for Green Capital, "What is a Green Bank," accessed September 2022. Avery, W. Barron A., McCarthy, et al., "Inflation Reduction Act Creates $27B 'Green Bank' Fund for Clean Energy Projects, But False Claims Risk Exist," August 2022.

Fournier, Eric Daniel, Cudd, Robert, et al., "On energy sufficiency and the need for new policies to combat growing inequities in the residential energy sector," June 2020.
Coalition for Green Capital, "What is a Green Bank," accessed September 2022.
Coalition for Green Capital, "NY Green Bank Shows the Way for Private Capital to Follow," October 2021.
Coalition for Green Capital, "NY Green Bank Shows the Way for Private Capital to Follow," October 2021.

The IRA also provides the option for wind projects to claim the energy investment tax credit (ITC) in lieu of the PTC.[39] The IRA would modify and extend the ITC for investments in small wind property through the end of 2024 at a base rate of 6 percent. Similar to the PTC, these amounts could increase if they

[37] The bonus credit would be 10 percent of the credit amount. Under the IRA, in 2024 the maximum PTC that large facilities not meeting domestic content requirements would be limited to 90 percent. However, this limit could be waived if domestically sourced materials are not available or if the inclusion of domestically-sourced materials in the facility's construction would increase cost by more than 25 percent. Congressional Research Service, "Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376)," August 10, 2022. P. 6.
[38] An energy community is defined in the IRA as a brownfield site; an area which has or had certain amounts of direct employment or local tax revenue related to activities in oil, gas, or coal and has an unemployment rate at or above the national average; or a census tract or adjoining tract in which a coal mine closed after 1999, or in which a coal-fired power plant was retired after 2009. U.S. Congress, "Inflation Reduction Act of 2022," August 2022. Pp. 258-259.
[39] U.S. Congress, "Inflation Reduction Act of 2022," August 2022. Pp. 284-291.

meet certain requirements.[40] Like the PTC, an ITC bonus credit could be received if the wind project meets certain domestic content requirements.[41] However, unlike the PTC, these additional credits are not percentage increases, and instead are percentage point increases to the tax credit. Additionally, the IRA allows for an increase in energy credits beyond the ITC in the form of "environmental justice solar and wind capacity" credits in each calendar year 2023 and 2024.[42]

In sum, the IRA extends and modifies the federal tax credits available to wind energy projects, offering an industry that has benefitted from the PTC predictability in the next few years. Along with improvements in technology and a host of state-level policies, the PTC has been instrumental to wind power additions in recent years, with 13.4 gigawatts (GW) of on-shore wind energy added in 2021.[43] For example, in 2021, twelve wind projects were partially repowered, with the primary motivation being to re-qualify for the PTC.[44] Prior to the passage of the IRA, the Energy Department's future outlook reported that total annual on-shore wind additions would generally decline through 2023 in part because of the expiration of the federal PTC.[45]

The domestic content requirements in the IRA to qualify for the PTC may lead to greater domestic manufacturing content for some wind turbine components, but the impact on the U.S. industry will depend on the capabilities of a U.S. industry that is reliant on foreign imports to ramp up production for certain wind project components. In 2021, imports of wind turbine components totaled approximately $3.1 billion, with the majority of imports of wind equipment sourced from Mexico, Spain, and India. In the same year, domestically produced blades and hubs only made up approximately 15-25 percent of all blade and hubs components used in new (and repowered) U.S. wind projects. Domestic manufacturing content for larger components such as nacelle assembly and towers, however, made up a higher share of the wind turbine components used in these projects.[46] From 2012 through 2020, domestic manufacturing capacity for nacelle assembly, tower and blade manufacturing capacity remained stable, with nacelle assembly at approximately 13 GW/year in 2012 and declining to 12.3 GW/year in 2020. Domestic capacity for tower and blade manufacturing increased from approximately 7 to 8 GW/year each in 2012 to around 10 GW/year in 2020. Domestic blade manufacturing capacity, however, saw a 50 percent decrease in 2021 to approximately 4.6 GW/year.[47] According to a recent Department of Energy report, a combination of factors contributed to a weakening in domestic wind turbine components

[40] The ITC could increase to 30 percent if wind projects meet registered apprenticeship requirements and pay prevailing wages during construction and during the first five years of operation. An increased credit amount would also be available if projects are located in an energy community. Congressional Research Service, "Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376)," August 10, 2022.
[41] To earn this credit, the wind project must meet the same domestic content requirements set out for the ITC.
[42] The IRA allows for 10 percent of environmental justice tax credits for wind projects that are located in a low-income community or on Native American land. Wind projects that are part of a low-income residential building project or qualified low-income economic benefit project would be eligible for an additional 20 percentage points. In totality, projects with domestic content that are also located in energy communities could be eligible for a 50 percent ITC. To qualify, wind facilities would need to have nameplate capacity of 5 megawatts or less, and qualifying properties would include energy storage properties installed in connection with wind facilities and interconnection property. U.S. Congress, "Inflation Reduction Act of 2022," August 2022. Pp. 284-291.
[43] U.S. Department of Energy. "Land-Based Wind Market Report: 2022 Edition," August, 2022.
[44] U.S. Department of Energy. "Land-Based Wind Market Report: 2022 Edition," August, 2022. p. ix.
[45] U.S. Department of Energy. "Land-Based Wind Market Report: 2022 Edition," August, 2022. p. xii.
[46] The share of domestic content for wind towers used in U.S. wind projects in 2021 was approximately 55-70 percent. The share of domestic content for nacelle assembly was estimated at approximately 85 percent. U.S. Department of Energy. "Land-Based Wind Market Report: 2022 Edition," August, 2022. pp. 20-21.
[47] Three blade manufacturing plants idled or closed production in 2021: Molded Fiber Glass, Vestas, and TPI Composites. Department of Energy. "Land-Based Wind Market Report: 2022 Edition," August 2022. p. 15.

production, such as pressure from foreign suppliers, competition among domestic OEMs, and uncertainty in the future deployment for land-based wind projects.[48]

The IRA faces the headwinds outlined above, but the inclusion of domestic content requirements in the expansion and modification of the PTC may see an increase in sourcing of domestic wind turbine components for future wind projects. However, it is too early to tell if the additional bonus credit of domestically sourced content will make a difference in the sourcing of these components. The largest impact may be seen in certain segments of the domestic industry, such as the production of components in which the U.S. industry contributes a large share in wind power projects.

Nuclear Energy

The U.S. is the largest producer of nuclear energy in the world, accounting for 30 percent of global nuclear energy output.[49] In the U.S., more electricity is produced by nuclear than wind, solar, and hydropower combined, making it the country's largest carbon-free energy source (table 2.2).[50] The industry helps the country avoid releasing 470 million metric tons of carbon each year, equivalent to the output of 100 million cars.[51] However, much of the country's nuclear fleet is aging, as the average commercial nuclear power reactor in the U.S. is around 40 years old.[52] Both the scale and age of nuclear energy production facilities in the U.S. represent a large domestic market opportunity. The IRA's tax and investment incentives can help U.S. nuclear technology and production companies take advantage of this.

The IRA includes multiple provisions to support nuclear power through changes in tax policy and direct investments.[53] If wage and labor requirements are met, this credit will provide plants with up to $15 per megawatt-hour of energy produced.[54] The second tax incentive involves technology-neutral tax credits for new energy production.[55] Plants can choose either a $25 per megawatt-hour credit for the first 10 years of plant operation or a 30 percent investment tax credit on new zero-carbon power plants placed into operation in 2025 or after.[56] Current tax credits are specific to renewable energy, putting nuclear energy at a competitive disadvantage compared to the likes of wind and solar.[57] The creation of technology-neutral tax credits would eliminate this disadvantage. This could incentivize increased commercial investment in the industry and help spur U.S. manufacturing of nuclear technology equipment.

Another provision in the IRA aimed at future development of the U.S. nuclear industry is the $700 million of funding for domestic supply chain development of High-Assay Low-Enriched Uranium (HALEU),

[48] Department of Energy. "Land-Based Wind Market Report: 2022 Edition," August 2022. Pp. 15-16.
[49] International Atomic Energy Agency, "Nuclear Share of Electricity Generation in 2021," accessed September 2022. Kumar, Hemanth, "The Top Ten Countries Producing the Most Nuclear Energy," February 2021.
[50] U.S. Energy Information Administration, "Frequently Asked Questions (FAQs) - What Is U.S. Electricity Generation by Energy Source?" February 2022.
[51] U.S. Department of Energy, "Advantages and Challenges of Nuclear Energy," March 2021.
[52] U.S. Energy Information Administration, "Frequently Asked Questions (FAQs) - How Old Are U.S. Nuclear Power Plants, and When Was the Newest One Built?" February 2022.
[53] U.S. Congress, "Inflation Reduction Act of 2022," August 2022.
[54] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022.
[55] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022. U.S. Congress, "Inflation Reduction Act of 2022," SEC 13702, August 2022. Pp. 470-490.
[56] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022.
[57] Greene, Stephen S., "The Inflation Reduction Act Reinforces Nuclear Energy's Role as a Climate Solution," August 2022.

uranium enriched between 5 and 20 percent.[58] This provision provides funding for Section 2001(a)(2) of the Energy Act of 2020, for licensing and regulation of special nuclear material fuel fabrication and enrichment facilities, research, development, and financial assistance for commercial entities to design and license transportation packages, and civilian domestic and commercial research.[59] Over 20 U.S. companies are developing advanced nuclear reactors, many requiring HALEU.[60] The existing fleet of nuclear reactors, by comparison, runs on uranium enriched up to 5 percent.[61] Russia is currently the only country with commercial-scale HALEU production.[62] Establishing a domestic HALEU supply could aid U.S. developers of advanced nuclear reactors by providing onshore access to a next generation fuel supply and reduce U.S. import reliance from Russia, a single source supplier currently subject to a variety of international sanctions.[63]

The last major nuclear provision in the IRA is the allocation of $150 million to the Office of Nuclear Energy for infrastructure and plant projects at the Department of Energy National Laboratories.[64] This funding can help support the National Laboratories' research and development capabilities targeted at next-generation nuclear technology.[65] In 2015, the Utah Associated Municipal Power Systems, in partnership with the Idaho National Laboratory (INL), launched their Carbon Free Power Project, which calls for the construction of a Small Modular Reactor (SMR) power plant.[66] The plant will use technology from NuScale Power, a U.S. company with the first and only SMR to undergo design certification and review by the U.S. Nuclear Regulatory Commission.[67] In 2021, NuScale installed a simulation laboratory at the Center for Advanced Energy Studies, part of the INL.[68] This new laboratory will allow researchers, students, and operators to run control room simulations of NuScale's SMR, providing them with a better understanding of how these advanced reactors operate.[69] National Laboratory funding in the IRA for future projects like these can help train the domestic nuclear workforce aid U.S. researchers and companies like NuScale in the development of cutting-edge technology.[70]

[58] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022; U.S. Congress, "Inflation Reduction Act of 2022," SEC 50173, August 2022. Pp. 631-631.
[59] 42 U.S.C. 16281, "Energy Act of 2020," Sec. 2001(a)(2), Pp. 821-827.
[60] U.S. Department of Energy, "What Is High-Assay Low-Enriched Uranium (HALEU)?" April 2020.
[61] U.S. Department of Energy, "What Is High-Assay Low-Enriched Uranium (HALEU)?" April 2020.
[62] Greene, Stephen S., "The Inflation Reduction Act Reinforces Nuclear Energy's Role as a Climate Solution," August 2022. Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022.
[63] International Trade Administration, "Russia - Sanctions Framework," July, 2022.
[64] U.S. Congress, "Inflation Reduction Act of 2022," Sec. 50172(c), p. 630, August 2022.
[65] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022.
[66] Idaho National Laboratory, "Carbon Free Power Project - INL," accessed October 14, 2022. The Idaho National Laboratory is one of the Department of Energy's national laboratories.
[67] "NuScale SMR Simulation Lab Opens in Idaho," accessed October 12, 2022.
[68] "NuScale SMR Simulation Lab Opens in Idaho," accessed October 12, 2022.
[69] "NuScale SMR Simulation Lab Opens in Idaho," accessed October 12, 2022.
[70] "NuScale SMR Simulation Lab Opens in Idaho," accessed October 12, 2022.

Table 2.2 U.S. utility-scale electricity generation by source, amount, and share of total in 2021

Energy source	Billion kWh	Share of total
Total - all sources	4116	100.00%
Fossil fuels (total)	2504	60.80%
Nuclear	778	18.90%
Renewables (total)	826	20.10%
Wind	380	9.20%
Hydropower	260	6.30%
Solar (total)	115	2.80%
Biomass (total)	55	1.30%
Geothermal	16	0.40%
Pumped storage hydropower	-5	-0.10%
Other sources	12	0.30%

Note: Wind, hydropower, solar, biomass, and geothermal are subtotals of renewables. Source: U.S. Energy Information Administration

Market opportunities exist abroad as well. As countries around the world look to transition away from carbon intensive energy production, the role in nuclear energy is expected to grow. According to the International Atomic Energy Association's 2021 high case scenario projections, by 2050 global nuclear generating capacity is expected to double.[71] Much of the growth is expected to come from Asia.[72] China's plans for massive investment in nuclear energy include the construction of 150 nuclear reactors over the next 15 years. Japan is restarting many of its nuclear plants that had been shut down after the 2011 Fukushima disaster.[73]

The E.U. is also incorporating nuclear into its energy and climate agenda. In July, the European Parliament voted in favor of E.U. rules labelling nuclear energy as "green."[74] According to the Commissioner for Financial Services, Financial Stability, and Market Union, the taxonomy change is a "pragmatic proposal to ensure that private investments in gas and nuclear, needed for our energy transition, meet strict criteria."[75] The move seeks to diversify E.U. energy sources in order to reduce dependency on imported Russian gas and contribute to the bloc's carbon zero climate goals.[76] France, a supporter of the labelling change, produces 69% of its electricity from nuclear energy, more than any other nation.[77] The country has plans to invest over $53 billion in the construction of next generation nuclear reactors.[78]

U.S. firms are some of the most prominent producers of nuclear technology and equipment products in the world, with exports totaling $1.02 billion in 2021.[79] GE-Hitachi, an alliance between U.S.-based General Electric and the Japanese conglomerate Hitachi, is the largest player in the industry, and Westinghouse Electric Company is the fourth largest.[80] These companies are working on some of the

[71] International Atomic Energy Agency, "IAEA Increases Projections for Nuclear Power Use in 2050," September 2021.

[72] Mordor Intelligence, "Nuclear Power Market Size, Share," accessed September 2022.
[73] Mordor Intelligence, "Nuclear Power Market Size, Share," accessed September 2022; Hale, Erin and Power, John, "Asia Goes Nuclear as Climate, Ukraine Banish Memory of Nuclear Power," July 2022.
[74] Abnett, Kate, "EU Parliament Backs Labelling Gas and Nuclear Investments as Green," July 2022.
[75] European Commission, "EU Taxonomy: Vote by EP on Complementary Delegated Act," July 2022.
[76] European Commission, "EU Taxonomy: Vote by EP on Complementary Delegated Act," July 2022.
[77] Abnett, Kate, "EU Parliament Backs Labelling Gas and Nuclear Investments as Green," July 2022. International Atomic Energy Agency, "Nuclear Share of Electricity Generation in 2021," accessed September 2022.
[78] Alderman, Liz and Reed, Stanley, "Nuclear Power Could Help Europe Cut Its Russia Ties, but Not for Years," April 2022.
[79] U.S. Census, "FT900 U.S. International Trade in Goods and Services - Annual Revision," exhibit 15a, June 2022.
[80] Mordor Intelligence, "Nuclear Power Market Size, Share," accessed September 2022.

most advanced nuclear reactor innovations in the world, including modular water-cooled reactors, non-water reactors, and microreactors.[81] However, smaller U.S. nuclear companies are also on the cutting edge. One such company is U.S.-based TerraPower, a nuclear innovation company started by Microsoft founder Bill Gates.[82] TerraPower is planning to build its Natrium reactor, an advanced sodium-cooled nuclear reactor near a retired coal plant in Wyoming, a state that produces nearly 80 percent of its electricity from coal-fired power plants.[83] This and other demonstration projects supported by the Department of Energy, including U.S.-based X-energy's Xe-100 reactor, are among those that will require HALEU as their fuel source.[84] NuScale is working on deploying its advanced SMR technology across the globe, with projects in countries like Japan, South Korea, Jordan, and the United Kingdom.[85]

Despite the prominent position of American firms in the nuclear energy market, the U.S. still ran a $1.52 billion dollar trade deficit in nuclear technology products in 2021.[86] However, the nuclear provisions in the IRA look to increase the global competitiveness of American firms. The energy production tax credits, the investment in establishing a domestic HALEU supply, and the National Laboratories funding included in the law could potentially bolster the domestic industry's growth both at home and abroad.[87]

Hydrogen Energy

The Inflation Reduction Act contributed $2 billion to the Department of Energy National Laboratories with the goal of accelerating green energy research.[88] Hydrogen – or green hydrogen – is a clean fuel that produces only water when consumed in a fuel cell and has the potential to reduce a company's supply chain emissions. It is a growing fuel option in the transportation and electricity generation sectors, as it serves as an energy carrier that can store, move, and deliver energy that is produced from other clean or renewable sources.[89] Currently, gray hydrogen – produced from reformatting natural gas – makes up most of the hydrogen produced.[90] Electrolysis is the fastest growing green hydrogen production technique; it is the process of using electrical currents to split water into hydrogen and oxygen, typically taking place in a unit called an electrolyzer.[91]

Breakthrough research on green hydrogen and fuel cells have been a staple for researchers at offices within the U.S. Department of Energy (DOE) and their National Labs.[92] Examples include the National

[81] U.S. Department of Energy, "Advanced Reactor Technology Development Fact Sheet," January 2019.
[82] Clifford, Catherine, "What the Climate Bill Does for the Nuclear Industry," August 2022.
[83] Caponiti, ALice, "Next-Gen Nuclear Plant and Jobs Are Coming to Wyoming," November 2021.
[84] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022.
[85] "Current Projects | NuScale Power," accessed October 13, 2022.
[86] U.S. Census, "FT900 U.S. International Trade in Goods and Services - Annual Revision," exhibit 15a, June 2022.
[87] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022.
[88] U.S. Senate, "Summary of the Energy Security and Climate Change Investments in the Inflation Reduction Act of 2022," August 2022.
[89] U.S. Department of Energy, "Hydrogen Fuel Basics," accessed September 2022.
[90] Gray hydrogen is produced using coal or natural gas while green hydrogen is considered zero emission and uses renewable energy sources to split water into oxygen and hydrogen. Markets and Research, "Hydrogen Generation Market by Technology (SMR, POX, Coal Gasification, Electrolysis), Application (Refinery, Ammonia Production, Methanol Production, Transportation, Power Generation), Source (Blue, Green, Gray), Generation Mode, Region - Forecast to 2027," August 2022.
[91] Markets and Research, "Hydrogen Generation Market by Technology (SMR, POX, Coal Gasification, Electrolysis), Application (Refinery, Ammonia Production, Methanol Production, Transportation, Power Generation), Source (Blue, Green, Gray), Generation Mode, Region - Forecast to 2027," August 2022. U.S. Department of Energy, "Hydrogen Production: Electrolysis," accessed September 2022.
[92] DOE offices with researchers focused on hydrogen and fuel cells include the Office of Energy Efficiency and Renewable Energy, Office of Fossil Energy, Office of Nuclear Energy, and Office of Science. DOE National Labs with researchers focused on hydrogen and fuel cells include Argonne National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, National Energy Technology Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Pacific Northwest National Laboratory, and Savannah River Site. U.S. Department of Energy, "Federal Agency Sites," accessed September 2022.

Energy Technology Laboratory which focuses on fuel cells and the advanced gasification of the production of hydrogen and electrolysis; the Pacific Northwest National Laboratory performs research in hydrogen fuel processing, hydrogen storage, and hydrogen safety; and the Sandia National Laboratories' Hydrogen Program focuses on advancing the use of hydrogen as an energy carrier.[93]

Further green hydrogen projects include United Kingdom-based Linde developing a 24MW green hydrogen plant in Norway for the chemicals company Yara to use in the production of green ammonia and a 2 GW plant in Germany for the energy company RWE AG.[94] United Kingdom-based Shell PLC plans to build a 200 MW hydrogen electrolysis plant in Rotterdam with the aim of supplying ships with green hydrogen by 2024.[95] U.S.-based Air Products and Chemicals has made their name in gray hydrogen, but they plan to build a 2 GW green hydrogen plant in Saudi Arabia with plans to produce 600 tons of green hydrogen a day by 2026.[96] As companies such as these expand their green hydrogen production, the global hydrogen generation market is expected to reach $263.5 billion by 2027 with a 10.5 percent compound annual growth rate (CAGR). Additionally, growing demand for hydrogen in clean vehicles and rockets in the aerospace industry are driving demand up.[97]

[93] U.S. Department of Energy, "Federal Agency Sites," accessed September 2022.
[94] Green ammonia involves making ammonia using renewable or carbon free sources.Defiance, "Meet the 3 companies at the forefront of green hydrogen production," July 18, 2022.
[95] Defiance, "Meet the 3 companies at the forefront of green hydrogen production," July 18, 2022.
[96] Defiance, "Meet the 3 companies at the forefront of green hydrogen production," July 18, 2022.
[97] Markets and Research, "Hydrogen Generation Market by Technology (SMR, POX, Coal Gasification, Electrolysis), Application (Refinery, Ammonia Production, Methanol Production, Transportation, Power Generation), Source (Blue, Green, Gray), Generation Mode, Region - Forecast to 2027," August 2022.

Chapter 3: Environmental Justice & Impacts on Rural Communities

Dixie Downing, Robert Ireland, Steven LeGrand, Mitchell Semanik, and Brennan Taylor

The Inflation Reduction Act of 2022 contains environmental justice provisions that include large investments in disadvantaged and rural communities. The law provides funding to mitigate air pollution at ports, and this chapter provides an analysis of current projects – including carbon capture, utilization and storage, automated ports, and sustainable aviation fuel – to improve air quality for port communities. The law also invests money in agricultural research and biofuels, creating opportunities in the precision agriculture space and funding for current and new biofuel alternatives. Chapter 3 discusses provisions in the IRA to mitigate air pollution at ports and address critical environmental justice concerns as well as significant investments in rural communities in the form of biofuel advancements and research grants.

Environmental Justice: Air Pollution at Ports

Technologies to Mitigate Air Pollution at Ports

The emissions from diesel engines and air pollutants – such as benzene and formaldehyde – are known to pose significant health risks to sensitive populations.[98] The EPA and the World Health Organization have classified diesel exhaust emissions, benzene, and formaldehyde as known human carcinogens.[99] These pollutants are commonly found at sea and airports as nearly all cargo ships use diesel combustion engines, while formaldehyde is found in jet fuel exhaust.[100] Seaports specifically can affect neighboring water quality through excess runoff that may carry pollutants into nearby bodies of water.[101] While communities across the U.S. experience the negative externalities that these ports contribute, near-port communities bear the brunt of the economic impacts of these operations. Near-port communities are prominently minority and low-income areas which leads to these negative externalities disproportionately impacting these communities.[102]

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[98] U.S. Environmental Protection Agency, "Third Report to Congress: Highlights from the Diesel Emission Reduction Programv," February 2016. U.S. Environmental Protection Agency, "Health Assessment Document for Diesel Engine Exhaust," 2002.
[99] U.S. Environmental Protection Agency, "Formaldehyde CASRN 50-00-0 | DTXSID7020637," accessed September 2022. U.S. Environmental Protection Agency, "Diesel engine exhaust CASRN NA | DTXSID1024043," accessed September 2022. U.S. Environmental Protection Agency, "Benzene CASRN 71-43-2 | DTXSID3039242," accessed September 2022. International Agency for Research on Cancer, "Benzene," accessed September 2022.
International Agency for Research on Cancer, "Formaldehyde," accessed September 2022.
International Agency for Research on Cancer, "IARC: Diesel Engine Exhaust Carcinogenic," June 2012.
[100] Gallucci, Maria, "The Struggle to Make Diesel Guzzling Cargo Ships Greener," May 2018. University of Washington – Department of Atmospheric Sciences, "Reactive Chemistry in Aircraft Exhaust," accessed September 2022.
[101] U.S. Environmental Protection Agency, "Environmental Justice Primer for Ports: Impacts of Port Operations and Goods Movement," accessed September 2022.
[102] Gillingham, Kenneth and Haung Pei, "Air Pollution, Health, and Racial Disparities: Evidence from Ports", April 2021.

The White House and Congress look to expand upon initiatives to lower emissions at sea and airports by allotting $3 billion towards investment into zero-emission technology and equipment.[103] These technologies come with high initial capital costs and concerns about their practicality acting as high barriers to investment. There is also the adoption of fully automated and semi-automated port terminals which can greatly reduce emissions at ports.[104] Fully automated port terminals come with a variety of benefits to cost savings, productivity, and space utilization, and they can reduce carbon emissions by up to 50 percent.[105] For example, ships often have to lay anchor for one to three days when ports are busy – releasing harmful air pollutants to nearby communities; an automated system can tell other arriving ships to slow down.[106] However, the United States has lagged in adopting automation technology at ports compared to other countries around the world. Asia and Europe are home to the most automated port terminals with both continents housing five each (table 3.2).[107] The IRA's investments into the development of port infrastructure may lead to the implementation of new fully automated port terminals.

Table 3.1 Location and number of automated port terminals globally

Port Location	Automated	Semi-automated
Africa	-	Tangier Med
Asia	Xiamen, Shanghai, Qingdao, Tianjin, Nagoya	Incheon, Busan (3), Tokyo, Taipei, Kaohsiung (2), Singapore (2)
Australasia	Brisbane, Sydney, Melbourne	Brisbane (3), Sydney (2), Melbourne, Semarang, Suabaya
Europe	Rotterdam (4), Hamburg	Algeciras, Barcelona, Liverpool, London (2), Thamesport, Antwerp, Hamburg (2), Vado
Middle East	-	Abu Dhabi, Dubai
North America	Long Beach, Los Angeles	Virginia, New York/New Jersey, Lazaro Cardenas, Tuxpan

Notes: Australasia includes Australia, New Zealand, and Melanesia.Source: Bachkar, Khalid, and Densberger, Nicole Light, Towards accelerating the adoption of zero emissions cargo handling technologies in California ports: Lessons learned from the case of the ports of Los Angeles and Long Beach.

Carbon Capture, Utilization, and Storage

Carbon dioxide (CO_2) emissions at ports are a concern for environmental justice advocates as communities of color and lower income communities are disproportionately impacted by industry and power generation emissions at ports.[108] Carbon capture, utilization, and storage (also known as sequestration) (CCUS) is a process that captures carbon dioxide emissions from sources like

[103] Public Law 117-169, § 60102 (adding sec. 133 to Clean Air Act). Elliott, Nicole and Hettinger, Lauri, "The Inflation Reduction Act: Provisions and Incentives for Local Governments", October 13, 2022.
[104] Automated port tasks are the repetitive and heavy lifting tasks including yard management, port gates, stacking cranes, horizontal transport, and quay cranes. Yard management includes shipping container stowage and yard planning. Port gate automation speeds up transport by automating security, weigh bridges, and customs. Automated stacking cranes use lidar-based sensors to position containers. Horizontal transport includes the use of automated guided vehicles or automated straddle carriers to move containers from the stacks to the quay. Automated quay cranes are the most complex piece of automated ports as these cranes require advanced motor control systems to adjust for the swaying of a crane and the ship. Gardner, Nic, "A brief guide to container terminal automation," accessed September 2022.
[105] Park, Nam Kya and An, Yohan, "Financial Analysis of Automated Container Terminal Capacity from the Perspective of Terminal Operating Company," December 2020.
[106] Columbia Climate School, "How We Can Make Ports More Sustainable — And Why it Matters," September 2019.
[107] Priceonomics, "Why Aren't America's Shipping Ports Automated?" accessed September 2022.
[108] More information of the Greenhouse Gas Protocol's Scope emissions can be found in Part 2 of this working paper series. U.S. Environmental Protection Agency, "Ports Primer: 4.1 Port Impacts to Local Communities," accessed September 2022.

manufacturing facilities and power plants – either reusing or storing CO_2 so it will not enter the atmosphere.[109] Carbon dioxide is stored in geological formations like oil and gas reservoirs, coal seams, and deep saline reservoirs; these are structures that have stored fossil fuel materials for millions of years.[110] Technologies used to capture CO_2 at the source fall into three categories: post-combustion carbon capture (primarily used at power plants), pre-combustion carbon capture (primarily used in industrial processes), and oxy-fuel combustion systems.[111] The IRA includes funding to encourage investments and planning into CCUS at ports, electricity facilities, and other production facilities.[112]

In 2020, the global CCUS market was valued at $1.9 billion – with 10 out of 31 commercial operational facilities located on U.S. soil.[113] The industry is projected to reach $7.0 billion by 2030.[114] Current operating facilities have the capacity to capture 40 million metric tons of CO_2 per year. For context, the U.S. alone emitted 5 billion metric tons of CO_2 into the atmosphere in 2019.[115] Key players in the CCUS industry, listed in table 3.1, face significant issues related to high costs, transportation of captured CO_2, and water usage.[116] The biggest costs are associated with the energy and equipment needed for the carbon capture and compression phases, while some plants face decreased efficiencies due to increased energy and water usage required to keep carbon capture facilities operational.[117]

Table 3.2 Key players operating in the global carbon capture, utilization and storage industry

Headquarters	Select producers
United States	Fluor Corporation, Exxon Mobil Corporation, Schlumberger Ltd., Honeywell International Inc., Halliburton, Talos Energy Inc.
Japan	Mitsubishi Heavy Industries, Ltd., JGC Holding Corporation
Netherlands	Energie Beheer Nederland B.V. (EBN)
Norway	Aker Solutions
United Kingdom	Royal Dutch Shell PLC

Source: Allied Market Research (date?)

To address emission at ports, CCUS technology producing firms are working with port authorities to capture and store emissions that are harmful to local communities. In the United States, Talos Energy Inc. and Howard Energy Partners have entered into an agreement with the Port of Corpus Christi Authority – known as the Coastal Bend Carbon Management Partnership – to pursue commercial carbon capture opportunities on-site at the port in Corpus Christi, TX.[118] The port is one of the largest in the U.S.

[109] U.S. Department of Energy, "Carbon Capture, Utilization & Storage," accessed September 2022.
[110] U.S. Department of Energy, "Carbon Capture, Utilization & Storage," accessed September 2022.
[111] Resources for the Future, "Carbon Capture and Storage 101," May 2020.
[112] Public Law 117-169, § 13104.
[113] Allied Market Research, "Carbon Capture, Utilization, and Storage (CCUS) Market by Service (Capture, Transportation, Utilization, and Storage), Technology (Pre-Combustion Capture, Oxy-Fuel Combustion Capture, and Post-Combustion Capture), and End-Use Industry (Oil & Gas, Power Generation, Iron & Steel, Chemical & Petrochemical, Cement, and Others): Global Opportunity Analysis and Industry Forecast, 2021-2030v," August 2021. Resources for the Future, "Carbon Capture and Storage 101," May 2020.
[114] These projections were created before the implementation of the IRA. The forecasted growth of the market will most likely be larger than experts previously projected. Allied Market Research, "Carbon Capture, Utilization, and Storage (CCUS) Market by Service (Capture, Transportation, Utilization, and Storage), Technology (Pre-Combustion Capture, Oxy-Fuel Combustion Capture, and Post-Combustion Capture), and End-Use Industry (Oil & Gas, Power Generation, Iron & Steel, Chemical & Petrochemical, Cement, and Others): Global Opportunity Analysis and Industry Forecast, 2021-2030v," August 2021.
[115] Global CCS Institute, "Global Status of CCS 2021," 2021.
[116] Resources for the Future, "Carbon Capture and Storage 101," May 2020.
[117] Resources for the Future, "Carbon Capture and Storage 101," May 2020.
[118] Port of Corpus Christi, "Port of Corpus Christi Enters Into Agreement with Talos Energy and Howard Energy Partners for Carbon Capture and Sequestration Opportunities," February 2022.

supporting over 100,000 jobs and accommodating over 7,000 vessels a year.[119] The Port of Rotterdam is the EU's largest port, and it generates 15 percent of the Netherlands' carbon emissions; it is also the home to the Porthos project (Port of Rotterdam CO_2 Transport Hub and Offshore Storage).[120] The Porthos project – developed by the Port of Rotterdam Authority, Gasunie, and EBN – will capture port CO_2 emissions and store them 3 kilometers below the North Sea starting in 2024.[121]

Sustainable Aviation Fuel

According to the Inflation Reduction Act of 2022, sustainable aviation fuels (SAF) are liquid fuels produced in the United States that consist of synthesized hydrocarbons, are derived from biomass (not including palm fatty acid distillates), meet the requirements of either ASTM International Standard D7566 or D1655 Annex A1, and achieve at least a 50 percent lifecycle greenhouse gas emissions reduction when compared with petroleum-based jet fuel.[122]

Despite a relatively brief history of SAF usage by airlines, there has been a noticeable increase in the amount of SAF purchases in recent years. United Airlines was the first airline to regularly use SAF in 2016 and by April 2022, 450,000 flights from 50 different airlines had used SAF.[123] Airline purchases of SAF offtake volumes totaled 9.2 billion liters in 2021, compared to a pre-pandemic high of 3.5 billion liters in 2015. Through September 2022, offtake volume purchases totaled 16.0 billion liters, showing a continued increase in demand for SAF.[124] This trend is expected to continue as SAF becomes an increasingly important method through which airlines can reduce aviation-related greenhouse gas emissions. According to International Air Transport Association, airlines will depend on increased SAF use to reduce 65 percent of greenhouse gas emissions to achieve net zero carbon by 2050.[125]

SAF produces fewer greenhouse gas emissions and has the potential to reduce a company's Scope 3 emissions, but it is more expensive to produce than petroleum-based jet fuel.[126] The IRA has two provisions that incentivize additional U.S. production and use of SAF, and therefore reduce greenhouse gas emissions: the alternative fuel and low-emission aviation technology program and the sustainable aviation fuel credit. The alternative fuel and low-emission aviation technology program provides two categories of SAF-related grants through September 30, 2026. The first category of grants appropriates $244,530,000 for SAF production, transportation, blending, and storage. The second category of grants appropriates $46,530,000 for technologies that improve aircraft fuel efficiency, increase SAF use, or otherwise reduce aircraft-related greenhouse gas emissions.[127] The second provision provides a credit for the sale or use of SAF in the United States. This credit is equal to $1.25 per gallon plus an additional

[119] Port of Corpus Christi, "Port of Corpus Christi Enters Into Agreement with Talos Energy and Howard Energy Partners for Carbon Capture and Sequestration Opportunities," February 2022.
[120] International Energy Forum, "In Europe's largest port, collaboration is key to cutting CO2 emissions," July 2021.
[121] International Energy Forum, "In Europe's largest port, collaboration is key to cutting CO2 emissions," July 2021. Porthos, "CO2 reduction through storage under the North Sea," accessed September 2022.
[122] Public Law 117-169, § 40007(e)(7).
[123] International Air Transport Association, "Net Zero 2050: Sustainable Aviation Fuels," June 2022.
[124] Major suppliers of SAF include Gevo, Fulcrum, and Alder Fuels while major purchases of SAF include United Airlines, Delta Airlines, and OneWorld. International Civil Aviation Organization, "SAF Offtake Agreements," accessed September 2022.
[125] International Air Transport Association, "Net Zero 2050: Sustainable Aviation Fuels," June 2022.
[126] More information on the Greenhouse Gas Protocol's Scope emissions can be found in Part 2 of this working paper series. Herbert, John, "Sustainable Aviation Taking Off Thanks to Inflation Reduction Act," August 2022.
[127] Public Law 117-169, § 40007(a).

$0.01 per percentage point by which the SAF exceeds the 50 percent lifecycle greenhouse gas emission reduction requirement (up to a maximum $0.50 credit).[128]

Impacts on Rural Communities: Spotlight on Precision Agriculture and Biofuels

Precision Agriculture

The IRA provides $3.1 billion in loans to agricultural operations that are at risk of defaulting on loans, and $2.2 billion in loans to farm operators determined to have experienced discrimination.[129] These loans can potentially be used by farm operators to purchase precision agriculture (PA) equipment, which tend to be capital intensive.

Also known as variable rate farming and site-specific farm management, PA is a data-driven approach to production that allows farmers to manage crops in more detail rather than to the field “average.”[130] PA is a suite of technologies based around geographic position data that allow farmers to tailor production inputs to specific areas of a field, which often have variations in yields.[131] This approach can allow farmers to monitor indicators like yields and soil nutrients to then vary applications of fertilizers and pesticides potentially down to the centimeter. Approximately 25 percent of farms in the United States use some form of PA technology, (self-driving tractors are often the first piece of technology adopted).[132] The PA adoption rate increases for larger farms growing row crops, with major row crop producing states such as Iowa seeing adoption rates around 50 percent.[133]

The environmental benefits from PA stem from the ability to target inputs to precisely where they are needed instead of applying them uniformly across an entire field. PA reduces the usage of carbon intensive products such as fertilizers by 7 percent – potentially reducing the negative environmental effects associated with their use. Fossil fuel use can decrease by size percent with PA technologies. The productivity gains from PA, estimated at 4 percent, can potentially, though not necessarily, allow for less land to be used for farming.[134] The data produced through PA can be used to verify certain farm practices that can then potentially be used to administer credits for sustainable farming practices, like no-till farming which stores carbon in the soil.[135]

Biofuels

The IRA provides extensive support for biofuels providing $500 million over ten years to support U.S. ethanol and biodiesel production. The U.S. Secretary of Agriculture can allocate the authorized funds for grants “to increase the sale and use of agricultural commodity-based fuels through infrastructure improvements.” This entails, among other things, “installing, retrofitting, or otherwise upgrading fuel

[128] Public Law 117-169, § 13203 (adding § 40B to Internal Revenue Code of 1986).
[129] Public Law 117-169, §Sections 22004 (amending 7 U.S.C. § 8103).
[130] U.S. Department of Agriculture’s Agriculture Research Service, “Under the Microscope,” January 2021. Ashworth, Amanda and Owens, Philip, “Benefits and Evolution of Precision Agriculture,” July 16, 2021; Davis, Glenn, Casady, William W., et al., “Precision Agriculture,” accessed September 2022; National Institute of Food and Agriculture, “Precision Agriculture in Crop Production,” accessed September 2022.
[131] Davis, Glenn, Casady, William W., et al., “Precision Agriculture,” accessed September 2022.
[132] Abbot, Chuck, “Heartland Embraces Precision Agriculture Practices,” August 2021.
[133] Abbot, Chuck, “Heartland Embraces Precision Agriculture Practices,” August 2021.
[134] *The Environmental Benefits of Precision Agriculture in the United States*, 2022.
[135] *2021 Sustainability Report*, 2021.

dispensers or pumps and related equipment, storage" and "building and retrofitting home heating oil distribution centers or equivalent entities and distribution systems for ethanol and biodiesel blends."[136]

Biofuels are a liquid fuel derived from plants or animals that have an energy function and are typically used as transportation fuel. The two main biofuels are ethanol and biodiesel. Although both are derived from biological materials, they have important differences, especially related to their chemical properties, production process, and the type of engines in which they are used. Ethanol is an alcohol that can be derived by fermenting an agricultural product such as corn.[137] Biodiesel, in contrast, is a type of diesel fuel derived from vegetable oils, animal fats, or recycled restaurant grease.[138] Ethanol is used as a fuel blend in gasoline engines (spark-fired ignition); biodiesel is used as fuel blend in diesel engines (fuel compression-ignition).[139] The biofuel market in the United States is driven by the Renewable Fuel Standard (RFS) which requires refiners or importers of gasoline or diesel to blend biofuels with their conventional fuels.[140]

Although incorporated into the decarbonization strategies of the United States and other countries, biofuels are environmentally controversial. When burned, such as in vehicles, biofuels emit carbon dioxide and other pollutants.[141] The fertilizers used to produce the agriculture feedstock for biofuels can cause soil and water contamination.[142] In addition, production of fertilizers uses large amounts of fossil fuels.[143] Production of biofuels requires enormous amounts of land, which alternatively could be used for more permanent carbon sinks. A recent study by scientists found that "the production of corn-based ethanol in the United States has failed to meet the policy's [RFS's] own greenhouse gas emissions targets and negatively affected water quality, the area of land used for conservation, and other ecosystem processes."[144]

The United States is a major producer and exporter of ethanol and biodiesel. Table 3.3 presents the name and location of the largest U.S. producers of ethanol and biodiesel.[145]

Table 3.3 Major U.S. producers of ethanol and biodiesel

Products	**Select major U.S. producers**
Ethanol	Poet Biorefining (South Dakota), Valero Energy (Texas), Archers Midland Daniels (Illinois), Green Plains (Nebraska), Marquis Energy (Illinois).
Biodiesel	Renewable Energy Group[146] (Iowa), Marathon Petroleum (Ohio), World Energy (Massachusetts), RBF (Texas), Cargill (Minnesota)

Sources: Statista

[136] Public Law 117-169, § 22003 (amending 7 U.S.C. § 8103).
[137] Two of the largest producers of ethanol are the United States and Brazil; in the United States, ethanol is predominantly derived from corn while in Brazil, ethanol is primarily derived from sugar cane.
[138] In the United States, biodiesel is predominantly derived from soybeans.
[139] U.S. Department of Energy, "Biofuel Basics," accessed September 13, 2022; U.S. Energy Information Administration, "Biofuels Explained," July 2022.
[140] Marrero, "Where is U.S. Ethanol Going?," January 2019.
[141] DeCicco et al., "Carbon Balance Effects of U.S. Biofuel Production and Use," August 2016.
[142] Lark et al., "Environmental Outcomes of the US Renewable Fuel Standard," December 2021.
[143] Woods et al., "Energy and the Food System," 2010; Smil, "How the World Really Works," 2022, 24.
[144] Lark et al., "Environmental Outcomes of the US Renewable Fuel Standard," December 2021.
[145] Statista, "Leading producers of ethanol by capacity in the United States as of 2021," 2022. Statista, "Leading producers of biodiesel by capacity in the United States as of 2022," 2022.
[146] The Renewable Energy Group was acquired by petroleum producer Chevron in June 2022.

Chapter 4: Consumer Energy Costs

Dixie Downing

With the goal of reducing energy costs and utility bills for consumers, the Inflation Reduction Act of 2022 includes direct incentives for consumers to make more energy efficient decisions. These incentives include tax credits, consumer home energy rebate programs, and a grant program to make affordable housing more energy efficient.[147] The tax credits incorporate a 10-year extension on existing credits for wind and solar and include credits to make electric HVAC, water heaters, and heat pumps more affordable.[148] The law also includes consumer home energy rebate programs with the goal to electrify home appliances and add energy efficient retrofits to existing household necessities.[149] Chapter 4 focuses on the industries impacted by the consumer incentives introduced in the IRA including household appliances, heat pumps, and residential solar.

Industries Impacted by the Consumer Home Energy Rebate Programs

Household appliances or systems count for a substantial share of consumer energy usage and costs. With air conditioning and heating leading the way (table 4.1), the IRA paves the way for more energy efficient and lower cost consumer decision-making.[150]

Table 4.1 Percentage of average residential energy usage by household appliance and system

Household appliance	Percentage of average residential energy use
Air conditioning and heating	43.1
Water heating	13.6
Appliances	10.3
TV and media equipment	3.9
Lighting	2.8
Other	26.2

Note: Air conditioning and heating includes space cooling, space heating, furnace fans, and boiler circulation pumps. Appliances includes washers, dryers, indoor cooking appliances, refrigeration, freezers, and dishwashers. TV and media equipment includes home entertainment equipment and computers. Other includes electronic devices, heating elements, motors, outdoor grills, natural gas and propane-fueled systems, pool and spa heaters, and backup generators. Source: U.S. Energy Information Administration

The U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE) have for many years provided consumers with a list of Energy Star products that are the same as standard products – while using less energy.[151] These products include both foreign and domestic manufacturers of household appliances (table 4.2).[152] Qualified refrigerators are considered to be 15 percent more energy efficient, light bulbs use 66 percent less energy, furnaces are considered to be 15 percent more energy

[147] Public Law 117-169, §§ 50122 and 50123.
[148] U.S. Senate, "Summary of the Energy Security and Climate Change Investments in the Inflation Reduction Act of 2022," August 2022.
[149] Public Law 117-169, § 50122.
[150] U.S. Energy Information Administration, "U.S. Energy Outlook 2022," March 2022.
[151] Energy Star, "What Makes a Product ENERGY STAR?" accessed August 2022.
[152] Energy Star, "Space Heaters," accessed August 2022. Energy Star, "Energy Star," accessed August 2022.

efficient, and plugged-in TVs use 3 watts or less when switched off – compared to a standard TV that consumes 6 watts on average when switched off.[153]

Table 4.2 Energy star certified products and select producing firms

Products	Select companies with Energy Star certified products	Qualified U.S. region
Water heaters	LG (South Korea), Reliance Water Heaters (U.S.), Rheem (U.S.),	All regions
Central air conditioners	American Standard (U.S.), Carrier (U.S.), Daikin (Japan), Fujitsu (Japan), Lennox (U.S.), LG (South Korea), Luxaire (U.S.), Mitsubishi (Japan)	All regions
Furnaces	Carrier (U.S.), Fujitsu (Japan), Lennox (U.S.), Rheem (U.S.)	South, Southwest, select states: AR, CA, KY, MD, NV, and OK
Refrigerators	Danby (Canada), Dometic (Sweden), Frigidaire (Sweden), Keystone (U.S.), LG (South Korea), Samsung (South Korea),	All regions

Note: There are currently no Energy Star qualified space heaters. Source: Energy Star

10 years of consumer tax credits were included in the IRA to make homes more energy efficient and increase the percentage of clean energy used in residential homes.[154] The consumer tax credits cover heat pumps, rooftop solar, electric HVAC, and water heaters.[155] Recent data shows increases in the market for heat pumps and residential solar leading to more opportunities for U.S. and foreign solar companies (table 4.3).[156]

Table 4.3 Heat pumps and residential solar select major producers (2020)

Products	Select major producers
Heat pumps	Mitsubishi Electric (Japan), Daikin (Japan), Carrier (U.S.), Johnson Controls, Inc. (Ireland), Danfoss Power Solutions Co. (Denmark), Ingersoll Rand Company (U.S.)
Residential solar	Jinkosolar Holdings Co. (China), First Solar Inc. (U.S.), SolarEdge Technologies Inc. (Israel), Xinyi Solar Holdings LTD. (China), SMA Solar Technology (Germany),

Sources: Solar Energy Insights and ThomasNet

Heat pumps are often referred to as earth-coupled, ground-source, water-source, or air-source heat pumps used to heat and cool buildings.[157] Heat pumps in use have increased from 12.1 million in 2015 to 17.5 million in 2020 with most new heat pump installations located in new builds in the U.S.[158] More than 39 percent of homes in Alabama, North Carolina, South Carolina, and Tennessee used heat pumps for heating in 2020 – accounting for the highest percentage of heat pumps used by state.[159] California and Texas led in solar panel installations in new homes in 2020 and 2021 – with 8.5 million homes

[153] Energy Star, "What Makes a Product ENERGY STAR?" accessed August 2022.
[154] Public Law 117-169, § 50122(a)(1) (providing funding to remain available through September 30, 2031).
[155] Public Law 117-169, § 50122(c)(3).
[156] Solar Energy Insights, "The Top Solar Energy Companies by Revenue," 2020. ThomasNet, "Top Heat Pump Manufacturers and Suppliers," 2020.
[157] Downing, Dixie and Gracia, Fernando, "Geothermal Heat Pumps: Demand is Heating Up," September 2020, https://www.usitc.gov/publications/332/executive_briefings/ebot_demand_for_heat_pumps.pdf.
[158] In 2015, 76.9 percent of heat pumps were located in the Southeast region of the U.S. with most heat pump installations located in new builds. U.S. Energy Information Administration, "U.S. households' heating equipment choices are diverse and vary by climate region," April 2017. U.S. Energy Information Administration, "Highlights for space heating in U.S. homes by state, 2020," June 2022.
[159] U.S. Energy Information Administration, "Highlights for space heating in U.S. homes by state, 2020," June 2022.

supplied by solar energy in California and 1.1 million in Texas.[160] Florida, also known as the Sunshine State, nearly doubled its solar capacity in 2020 at 2,763 MW of capacity.[161]

Efforts to increase clean sources of electricity in residential communities continue with a $1 billion grant program to make affordable housing more energy efficient.[162] The EPA published a paper on local government efforts to improve energy efficiency in affordable housing.[163] Select programs include Smart Growth, Urban Heat Island Reduction, Transportation Control Measures, Energy Efficient Product Procurement, and Combined Heat and Power.[164] Smart Growth incorporates economic and community development plans that prioritize the environment and public health.[165] It can be integrated with Transportation Control Measures to take advantage of existing infrastructure offering more regional public transportation options and overall reducing the cost of living.[166] Urban heat islands combine dark colored buildings, paved surfaces, and decreased tree cover to create "islands" of heat that impact public health, increase energy usage, and reduce air quality.[167] These "islands" contribute to environment justice issues as lower-income communities are typically the most vulnerable to these impacts. Combined Heat and Power (CHP) refers to the simultaneous production of electricity and thermal energy.[168] The benefits of CHP are increased efficiency, reduced emissions, reduced costs, and increased reliability.[169]

Conclusions and Next Steps in Research

The Inflation Reduction Act of 2022 has the potential to cut the future costs of climate change through many of the key investments discussed throughout this paper while also focusing on uplifting U.S. industries and employment.[170] The development and implementation of new climate technologies could give domestic manufacturers a first mover advantage (FMA), as there is currently no widely accepted standard for climate technology networks to mitigate climate change.

Incentive programs for electric vehicle manufacturers and consumers were highlighted in the IRA – including new critical mineral requirements that could be troublesome for certain vehicles manufacturers and parts suppliers. Data showed that 49 out of the 72 critical minerals analyzed in this paper do not have U.S. production, creating supply chain issues for certain industries interested in benefitting from the IRA. The U.S. largely depends on imports of many of these materials. In most cases, each industry is highly concentrated, with only a few, or even one, primary supplier to the global market for a given commodity. Advanced manufacturers in the United States are thus currently reliant on many global value chains for access to the materials they need to produce the technologies covered by the IRA. The IRA incentives for EVs will incentivize increased investment in critical minerals and battery

[160] Chester, Matt, "These 10 States Are Leading Solar Energy Installation in 2022," June 2021.
[161] Chester, Matt, "These 10 States Are Leading Solar Energy Installation in 2022," June 2021.
[162] Public Law 117-169, § 13702 (amending § 48E on Internal Revenue Code of 1986).
[163] U.S. Environmental Protection Agency, "Energy Efficiency in Affordable Housing," 2011.
[164] U.S. Environmental Protection Agency, "Energy Efficiency in Affordable Housing," 2011.
[165] U.S. Environmental Protection Agency, "Energy Efficiency in Affordable Housing," 2011.
[166] U.S. Environmental Protection Agency, "Energy Efficiency in Affordable Housing," 2011.
[167] U.S. Environmental Protection Agency, "Energy Efficiency in Affordable Housing," 2011.
[168] U.S. Environmental Protection Agency, "Energy Efficiency in Affordable Housing," 2011.
[169] CHP power plants cover energy efficiency by producing both electricity and heat using less fuel than other energy plants; it reduces emissions by burning less fuel; it reduces costs by increasing efficiency and driving down operating costs; it increases reliability as CHP is an on-site energy plant and does not rely on a power grid. GE Gas Power, "Combined heat and power generation," accessed September 2022.
[170] White House, "New OMB Analysis: The Inflation Reduction Act Will Significantly Cut the Social Costs of Climate Change," August 23, 2022.

components farther upstream, which appears likely to lead to the creation of an upstream critical mineral and battery component supply chain outside of China that was either nascent or non-existent prior to release of the law. However, meeting all of the requirements will be challenging, and many EVs will not be immediately eligible for the full incentive. Future research will be able to examine the effect the IRA had on EV and EV battery supply chain investments.

This paper highlights the green energy provisions outlined in the IRA – including solar, wind, nuclear, and hydrogen energy. The IRA provides tax credits for domestic manufacturing of wind turbines and solar panels, tax credits for nuclear energy production, and investments into energy research at the U.S. Department of Energy's National Labs which specialize in hydrogen and nuclear energy research. While 80 percent of the key manufacturing stages of the solar panel supply chain reside in China, investments in the IRA have the potential to diversify the supply chain by funding domestic manufacturing of solar inputs and decreasing reliance on Chinese solar imports. The U.S. wind industry is predicted to benefit from the three-year extension to the PTC, but the industry's ability to qualify for any additional tax credits associated with the PTC or ITC will depend on the industry's capabilities to meet the associated requirements, such as those related to domestic content requirements or apprenticeship requirements. While too early to tell if the additional tax credits will make a difference in sourcing of wind turbine components, the largest impact may be seen in certain segments of the domestic industry where the U.S. industry has historically contributed to significant shares in wind power projects.

Green hydrogen and fuel cells are increasingly being used in multiple sectors as it serves as an energy carrier that can store, move, and deliver energy that is produced from other clean or renewable sources. This is an industry to monitor as widespread technologies are still in development, and the IRA's funding for research at the Department of Energy's National Labs could lead to more green hydrogen in the future. While previous incentive programs focused on renewable energy sources, the IRA included tax credits for nuclear energy producers creating technology-neutral credits which have the potential increase the nuclear industry's competitiveness with the solar and wind industries. Nuclear energy is the largest source of zero carbon energy in the U.S. but has stagnated in recent years. Future research can assess the impact of the IRA on domestic nuclear energy production as well as its effects on imports of next-generation nuclear fuel.

Environmental justice was a key issue addressed in the IRA. Investments into decreasing pollution at ports through carbon capture, utilization, and storage, increasing port automation and efficiency, and research into sustainable aviation fuel have the potential to increase air and water quality for port communities which are disproportionately communities of color or lower income communities. The IRA also provides loans for agricultural operations which could lead to higher purchases of precision agriculture equipment or more eco-friendly farming technology. Additionally, the IRA provides support for biofuels through funding for ethanol and biodiesel production. Outlined in this chapter were key issues associated with biofuels and the development of eco-friendly solutions to pollution at ports that may impact funding established through the IRA. As many of these technologies are still in development, further research within the next 3 to 10 years should be done to evaluate the impacts of the IRA on port technologies, biofuels, and precision agriculture.

Finally, efforts to decrease consumer energy costs were outlined throughout the IRA and highlighted in the paper. The IRA provides direct incentives for consumers in the form of tax credits to choose more ecofriendly options including residential solar, heat pumps, and lower energy water heaters, central air conditioners, furnaces, and refrigerators. Tax credits are a means of influencing consumer behavior, and more data collected in 2–5 years will determine if the IRA’s tax credits made an impact on consumer decision-making.

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Appendix A

Table A.1 Critical minerals and chemicals identified in the IRA

Species (min. purity)	HTSUS line(s)	Global conc.	Global sources	U.S prod.	U.S. reserves	U.S. imports
Alumina (99)	2606.00	4,073	AU (53) ID (35)	1,000 kt	N/A	4.1 Mt
Aluminum (99.9)	7601.10	1,177	IN (18) CA (15) RU (14) NL (13)	880 kt	N/A	1.8 Mt
Ammonium paratungstate	2841.80.0010	5,271	CN (69) TW (22)	N	N/A	1.2 kt
Antimony (99.65)	8110.10	6,845	CN (82)	N	60 kt	6.9 kt
Antimony trisulfide (90)	2617.10	3,663	AU (51) RU (30)	N	N/A	33 t
Arsenic	2804.80	2,777	JP (39) DE (29) NL (18)	N	unk.	835 t
Barium Sulfate (80)	2511.10	2,031	CN (30) IN (24) MA (21)	W	N	1.4 Mt
Beryllium (99)	8112.19	9,803	US (99)	170 t	20 kt	38 t
Bismuth	8106.00	6,819	CN (82)	N	N	1.9 kt
Cadmium telluride	2842.90.90	2,613	DE (34) KR (26) PH (21) JP (19)	W	N/A	6.8 kt
Cerium (99)	2805.30.0010	6,221	CN (75) TH (23)	W	500 t	70 t
Cerium Oxide (99.9)	2846.10.0010	4,842	FR (65) CN (23) JP (11)	W	N/A	904 t
Cesium (99)	2805.19.90	4,559	CN (63) US (17) RU (16)	N	unk.	416 t
Cesium Carbonate	2836.99.5000	3,261	CN (48) DE (29) PL (11)	N	N/A	126 kt
Cesium formate	2915.12	4,779	CN (64) DE (24)	N	N/A	27 kt
Chromium (99)			RU (54) FR (22) GB (18)			
	8112.21	3,699	IE (32) DE (23)			10 kt
	8112.29	2,359	RU (22) CN (17)	N	620 kt	1.7 kt
Cobalt (99.6)	8105.20	2,775	CD (71)	700 t	69 kt	7.5 kt
Cobalt Sulfate	2833.29.10	3,453	CN (56)	N	N/A	1.9 kt
Copper-Beryllium	7405.00.6030	4,153	BE (62)	950 t	N/A	61 t
Dysprosium (99)	2805.30.0050	6,221	CN (75), TH (23)	N	50 t	34 t
Dysprosium-iron	2805.30.0090	6,221	CN (75), TH (23)	N	N/A	159 t
Erbium	2805.30.0090	6,221	CN (75), TH (23)	N	0.5 t	159 t
Europium (99)	2805.30.0050	6,221	CN (75), TH (23)	N	500 t	34 t

Species (min. purity)	HTSUS line(s)	Global conc.	Global sources	U.S prod.	U.S. reserves	U.S. imports
Europium oxide (99.9)	2825.90.90	3,211	CN (52) US (15) BR (11)	N	500 t	8.3 kt
Ferrochromium (60)			ZA (49) KZ (23) IN (12)			
	7202.41	3,077	RU (31) KZ (29)			449 kt
	7202.49	2,246	TR (17) NL (13)	N	N/A	66 kt
Ferroniobium	7202.93	7,976	BR (89)	N	N/A	9.8 kt
Ferrotungsten	7202.80	5,026	CN (61) RU (36)	N	N/A	33 t
Ferrovanadium	7202.92	2,282	CN (19) CZ (31) ZA (29)	N	N/A	2.9 kt
Fluorspar (97)	2529.22	4,384	MX (61) ZA (23)	N	4 Mt	328 kt
Fluorspar (99)	2529.22	4,384	MX (61) ZA (23)	22 Mt	4 Mt	328 kt
Gadolinium (99)	2805.30.0050	6,221	CN (75) TH (23)	N	500 t	34 t
Gadolinium oxide (99.9)	2846.90.2084	3,381	MY (52) US (25)	N	500 t	419 t
Gallium	8112.92.10	2,559	CN (38) TW (29) NL (10)	N	unk.	4.9 t
Germanium (99.99)	8112.99.10	2,394	BR (31) US (27) CN (25)	W	unk.	2.7 t
Germanium tetrachloride	2846.90.2084	3,381	MY (52) US (25)	W	N/A	419 t
Graphite (99.9)	3801.10	3,638	CN (57) JP (13) CH (10)	N	unk.	71 kt
Hafnium		unk.				
	8112.31	unk.				N/A
	8112.39		unk.	W	unk.	N/A
Holmium	2805.30.0090	6,221	CN (75) TH (23)	N	500 t	159 t
Indium (99)	8112.92.30	2,559	CN (38) TW (29) NL (10)	N	unk.	158 t
Indium oxide (99.9)	2825.90.90	3,211	CN (52) US (15) BR (11)	N	N/A	8.3 kt
Indium tin oxide	3824.99.39	1,506	DE (22) JP (22) IE (19)	N	N/A	185 kt
Iridium	7110.41.0010	5,005	ZA (69) BE (13)	N	unk.	1.9 t
Lanthanum	2805.30.0050	6,221	CN (75) TH (23)	N	500 t	34 t
Lithium (99.9)	2805.19.90	4,559	CN (63) US (17) RU (16)	W	750 kt	416 t
Lithium carbonate	2836.91	9,528	CL (98)	unk.	N/A	12 kt
Lithium hydroxide	2825.20	5,547	CN (73)	unk.	N/A	2.0 kt

Species (min. purity)	HTSUS line(s)	Global conc.	Global sources	U.S prod.	U.S. reserves	U.S. imports
Lutetium	2805.30.0090	6,221	CN (75) TH (23)	N	500 t	159 t
Magnesium	8104.11	8,789	CN (94)	W	substantial	6.1 kt
Manganese (99.7)	8111.00.47					16 kt
	8111.00.49	8,031	CN (89)	N	N	N/A
Manganese sulfate	2833.29.51	3,453	CN (56)	N	N/A	76 kt
Neodymium (99.9)	2805.30.0020	6,221	CN (75) TH (23)	W	100 t	14 t
Neodymium oxide (99.5)	2825.90.90	3,211	CN (52) US (15) BR (11)	W	unk.	8.3 kt
Neodymium-praseodymium oxide (99)	2846.90.2084	3,381	MY (52) US (25)	N	N/A	419 t
Nickel (99)	7502.10	1,605	CA (25) NO (23) SG (12) RU (11)	18 kt	340 kt	76 kt
Nickel sulfate	2833.24	2,869	TW (43) KR (29) BE (11)	N	N/A	1.3 kt
Niobium (99)	8112.92.40	2,559	CN (38) TW (29) NL (10)	N	170 kt	1.2 kt
Palladium	7110.21	2,993	RU (45) ZA (28) BE (12)	14 t	unk.	54 t
Platinum	7110.11	2,339	ZA (40) IT (11) RU (16)	4.2 t	unk.	51 t
Praseodymium	2805.30.0015	6,221	CN (75) TH (23)	N	500 t	0.005 t
Rhodium	7110.31	3,821	ZA (58) BE (17)	N	unk.	14 t
Rubidium	2805.19.90	4,559	CN (63) RU (16) US (17)	N	unk.	416 t
Ruthenium	7110.41.0030	5,005	ZA (69) BE (13)	N	unk.	18 t
Samarium	2805.30.0090	6,221	CN (75) TH (23)	N	500 t	159 t
Scandium	2805.30.0050	6,221	CN (75) TH (23)	N	unk.	34 t
Tantalum	8103.20	1,936	JP (27) CN (24) TH (18) CZ (14)	N	N	680 t
Tellurium (99)	2804.50.0020	3,094	CN (52) CA (17)	W	3.5 kt	42 t
Terbium	2805.30.0050	6,221	CN (75) TH (23)	N	500 t	34 t
Thulium	2805.30.0090	6,221	CN (75) TH (23)	N	500 t	159 t
Tin (99.99)	8001.10	2,537	ID (45) PE (16)	N	N	38 kt
Vanadium pentoxide	2825.30.0010	2,897	BR (36) RU (31) ZA (24)	N	45 kt	2.3 kt
Yttrium (99.9)	2805.30.0050	6,221	CN (75) TH (23)	N	unk.	34 t

Species (min. purity)	HTSUS line(s)	Global conc.	Global sources	U.S prod.	U.S. reserves	U.S. imports
Yttrium oxide (99.999)	2825.90.90	3,211	CN (52) US (15) BR (11)	N	N/A	8.3 kt

Source: U.S. Geological Survey, "Mineral Commodity Summaries," 2022; Goodman, "A Method of Estimating Global Supply Chain Risk and Predicting the Impacts of Regional Disruptions," 2022.
Note: "unk." is used throughout the table when a value is unknown, or data is not available. "min. purity" is the minimum purity of the species specified in the act (not all materials have a specified purity limit). "Global conc." is an HHI-form supply chain concentration measure as defined in Goodman (2022), which is reproduced in equation A1. "Global Sources" are the largest apparent producers of these materials as identified by the procedure defined in Goodman (2022); the numbers in parentheses are the apparent percentages of the global market they represent; countries are abbreviated using standard two-letter codes; data for hafnium isn't available from USGA or Goodman (2022). "U.S. Prod." is the amount of primary material produced annually in the United States based on available data from USGS; quantities are measured in million metric tons (Mt), thousand metric tons (kt), or metric tons (t); a "W" indicates the value is withheld by USGS to protect proprietary information; an "N" indicates no primary production. "U.S. Reserves" is the quantity of known deposits within the United States; an "N" indicates no proven reserves are known; "N/A" means this measure does not apply to this material (i.e., this material is not a primary product of mining or is covered by the entry for the primary metal or ore on the table). The U.S. Imports column are the quantities of each cited HTSUS line reported for 2021, note that most lines are categories containing out-of-scope materials.

$$\gamma_i = \sum_N \left[100 \frac{\sum_c E_{i,a,c} - \sum_c I_{i,a,c}}{\sum_N \left(\sum_c E_{i,a,c} - \sum_c I_{i,a,c} \right)} \right]^2 \quad \text{(A1)}$$

γ_i: the global concentration factor of commodity *i*.
i: A commodity within the set of commodities of which the United States is a net importer.
$I_{i,a,c}$: Imports of commodity *i* by country *a* from country *c*.
$E_{i,a,c}$: Exports of commodity *i* by country *a* to country *c*.
N: The set of all countries *a* that are net exporters of commodity