Investment Opportunities in Challenged Sectors Enabled by the Inflation Reduction Act

Fall 2023 Capstone Workshop for Citi Global Wealth Management

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List of Acronyms

AC	Alternating Current
ATB	National Renewable Energy Laboratory Annual Technology Baseline
BESS	Battery Energy Storage System
CCUS	Carbon Capture Utilization and Sequestration
CFPC	Clean Fuel Production Credit
CMA	Critical Materials Assessment
CO_2	Carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	Direct Air Capture
DC	Direct Current
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
ESGC	U.S. Department of Energy's Energy Storage Grand Challenge
EV	Electric Vehicle
FEED	Front-end Engineering and Design
FEOC	Foreign Entities of Concern
FTA	Free Trade Agreement
GJ	Gigajoules
GHG	Greenhouse Gases
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies
GW	Gigawatt
GWh	Gigawatt-hour
H_2	Hydrogen
HDV	heavy-duty vehicle
IRA	Inflation Reduction Act
IRS	Internal Revenue Service
ITC	Investment Tax Credit
kWh	kilowatt-hour
LCE	Lithium carbonate equivalent
LCOE	Levelized Cost of Energy
LFP	Lithium, Iron, and Phosphorus
LNG	Liquefied Natural Gas
MDV	Medium-duty vehicle
MGS	Metallurgical-grade silicon
MJ	Megajoules
MLPY	Million liters per year
MMbtu	Million British thermal units
MW	Megawatt
MWh	Megawatt-hour

NMC	Nickel, Manganese and Cobalt
NREL	National Renewable Energy Laboratory
OEMs	Original Equipment Manufacturer
PEM	Proton-exchange membrane
PTC	Production Tax Credit
PV	Photovoltaic
PWBM	Penn Wharton Budget Model
RFS	Renewable Fuel Standard
RNG	Renewable Natural Gas
SAF	Sustainable Aviation Fuels
SEIA	Solar Energy Industries Association
SMR	Steam Methane Reforming
SOE	Solid-oxide electrolyzer
VRE	Variable Renewable Energy

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Executive Summary

The 2022 Inflation Reduction Act (IRA) marked its first-year anniversary mid-august this year aims to raise tax revenue, cut healthcare costs, and allocate $500 billion in spending and tax breaks to boost private investment in clean energy and related sectors focused on decarbonization challenges. To many, the Act has lived up to its expectations as significant progress has been made in the IRA's first year.

While the Act incentivizes the traditional established renewable power sectors like solar, wind and hydro via both new and enhanced tax credits, the focus of this report is to highlight investment prospects created by the IRA for Citi Global Wealth Management clients among the more commercially challenged sectors.

The Act comes with its own sets of challenges and critics, including the ever-increasing cost estimates and the risk of provisions being amended or repealed in a subsequent administration. Nevertheless, the IRA represents a milestone in the United States' energy sector. Through a broad menu of incentives, the IRA seeks to motivate private investment for up to 16 business sectors related to climate change mitigation. This report provides an in-depth analysis for six of these sectors that have historically been commercially challenged and seem likely to benefit from the IRA's new and expanded incentives.

Underlying priorities for the Act include expanding U.S. manufacturing in decarbonization linked sectors, in targeted communities, raising labor standards, as well as addressing the supply chain security concerns that so much of the relevant equipment and critical minerals are supplied by China. An IRA innovation includes overlapping incentives for producers and purchases of targeted climate-mitigation equipment if manufactured at least in part within the U.S. Specifically, the sections 45X Production Tax Credits (PTC) and 48C Investment Tax Credits (ITC) have amped up investment in clean energy manufacturing across the country. This has resulted in the establishment of new facilities, expansion of existing production capabilities for a range of components used for wind and solar generation, and battery energy storage. The dual advantage of both supply side push (45X and 48C) and demand side pull (10% ITC/PTC adders for domestic content; crucial minerals sourcing requirements under 30D for EV batteries) will be crucial for allowing the key players in this sector to expand their footprint in battery production and storage.

In consideration of the multilayered incentives for U.S. manufacturing within the IRA, and the many subsequent announcements of expansions to domestic production, this report devotes much attention to the analysis the clean energy manufacturing sector. This report also selected five other heretofore commercially challenged sectors for closer examination as these are also showing signs of increased investment activity supported by the IRA's incentives: Clean Hydrogen, Utility-Scale Battery Energy Storage Systems (BESS), Clean Commercial Vehicles, Biofuels and Sustainable Aviation Fuels (SAF). In Part 2 this report includes a description of the applicable IRA provisions and lists of these key players within each of the sectors.

Clean Hydrogen must overcome challenges including its high cost of production to become the hoped for solution for many hard to decarbonize activities. The IRA introduced a new clean hydrogen production credit: the section 45V clean hydrogen PTC which ranges from $0.60 up to $3 per kilogram (kg) based on the life-cycle greenhouse gas (GHG) emissions rate of CO_2 produced at a qualifying facility during the facility's first 10 years of operation. This PTC is intended to subsidize clean hydrogen that is produced with electrolyzers fed by renewable energy (green hydrogen) as well as hydrogen produced from fossil fuel where carbon emissions are captured and sequestered (blue hydrogen). The so-called blue hydrogen also benefits from more generous PTC-type incentives for carbon capture and sequestration under the IRA. Many established energy companies appear to be targeting the clean hydrogen sector for investment.

BESS deployment received a crucial new ITC incentive under IRA, addressing limitations in the Pre-IRA structure confining ITC to batteries that were same-sited with renewables. The creation of a standalone tax credit for BESS projects, delinked from specific generation sources, and extended until at least 2033, simplifies processes and broadens financing options.

Clean commercial vehicles are supported with the new IRA incentives for electrification of medium-duty vehicles (MDV) and heavy-duty vehicles (HDV), including tax credits for vehicle purchases and charging infrastructure installations, are expected to significantly impact the market, potentially doubling or tripling the share of electrified trucks and vans in fleets by 2030.

Biofuels have benefited for some time from Federal blending mandates and incentives. These supports were expanded in the IRA through grant funding ($500 million), tax credits, and other incentives for facilities producing biogas. Ethanol producers can benefit from carbon sequestration credits, and the expansion of the 45Q tax credit enhances the economic viability of Carbon Capture, Utilization and Storage (CCUS) projects associated with ethanol production. Facilities involved in the production of renewable natural gas (RNG) have stand-alone incentives under the IRA; tax credits are no longer tied to producing electricity.

SAF production is far below the administration's goal of producing at least 35 billion gallons per year domestically by 2050. The IRA’s tax credits aim to drive this necessary expansion. However, this sector still has some big challenges particularly in securing adequate feedstock that it needs to overcome before it sees mature players investing in it.

For each of the six sectors analyzed, this report summarizes recent project announcements and employs a structured framework to assess the suitability of publicly listed market participants for Citi Global Wealth clients seeking to engage in the evolving post-IRA landscape. This assessment, based on a two-factor sorting matrix – ranks players on one axis for their leadership in each sector (largely a comparison of each player’s market share within each sector) and on the other axis ranks the priority each player places on the sector (an evaluation of the sector's importance to a company's overall business). The lower left quadrant of the sorting matrix identifies companies best positioned in theory to benefit from the IRA’s incentives within their respective sectors. Companies perceived as the sector leaders on the matrices are displayed in each of the sector analyses in Part 2 of this report.

The report’s findings are high-level and intended to serve as a guide to inform further research – they are not definitive investment recommendations.

About the client

As the IRA is projected to result in transformative levels of private investment, an in-depth analysis of how the IRA may create investment opportunities for its customers in selected sectors is the topic defined by this report's client Citi Global Wealth Management.

Citi Global Wealth Management combines all of Citi's resources to provide wealth management services to a wide range of clients, including family offices, the extremely wealthy, professionals, and the affluent. Within the wealth realm, the Private Bank is dedicated to serving the world's wealthiest individuals and their families. From 52 locations across 20 countries, Citi offers its services to more than 14,000 ultra-high net worth clients from nearly 100 nations. Wealth at Work focuses on the needs of the world's busiest professionals, ranging from lawyers to consultants to asset managers. Citigold and Citigold Private Client cater to other individuals seeking a dedicated team with complimentary financial planning, world-class investing capabilities, preferred pricing on select products and exclusive travel and lifestyle benefits. Citi Global Wealth offers customized, sophisticated, cross-border Global Wealth advising services across equities, fixed-income and multi-asset classes, to a clientele with global reach, seeking to protect and grow their wealth.

With these customers in mind, Citi Wealth Management aims to monitor how legislation, policy responses, and market trends shift investment opportunities and ultimately help their clients achieve their goals. Citi's request to the Capstone Team has been to analyze how the IRA might create investment opportunities among the commercially challenged sectors it addresses.

While this report does not aim to give specific investment recommendations, it aims to summarize the many innovative ways in which the IRA will incentivize private investment in key sectors of the greening economy that have so far been commercially challenged: Clean Hydrogen, BESS, Biofuels, SAF, Clean Commercial Vehicles and most importantly Domestic Manufacturing of Components for wind, solar, batteries and critical minerals. The report analyzes these targeted sectors, and how the tax credits enabled by the IRA would affect the evolution of these key sectors with the leading sector players identified.

This assessment will help Citi to analyze the influence of the IRA, and ultimately how the IRA enhances new investment prospects for Citi Global Wealth Management clients.

Analytical approach

As our aim is to provide a more targeted assessment, this analysis has been narrowed down to focus on six out of the 16 commercial sectors subsidized under the IRA. The request from Citi has been to focus on the commercially challenged sectors rather than those sectors benefiting from IRA which are already commercial and well established. Excluded from this review are the five established sectors including incumbents like power generation from solar, wind (both onshore and offshore), hydropower along with electric vehicle (EV) manufacture. These are sectors where incentives predate the IRA and their markets are more mature.

11 of the remaining sectors could be considered commercially challenged, some benefiting from new tax credits and others benefiting from the enhancement of existing tax credits. However even within these less established sectors, there are several where commercialization could be seen as still too distant. This would be the view for Advanced Nuclear, CCUS, Geothermal and Business

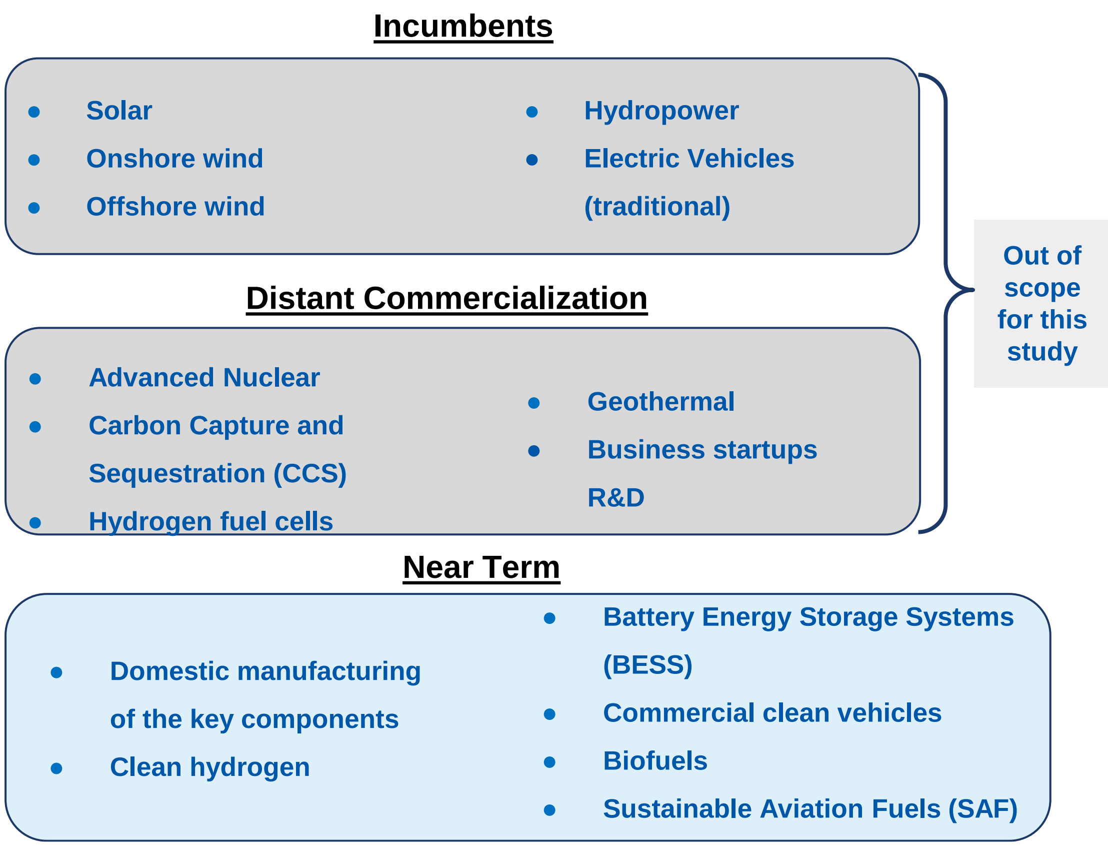
startups; the market activity in these sectors has been scarce or non-material among players who are too small or closely held. Accordingly, the focus of research for this report has been those commercially challenged sectors viewed as having a greater chance of near-term investments over the next decade and beyond due to their increased competitiveness enabled by the IRA.

Figure 1 depicts the process used to screen out certain sectors and the box in blue indicates the scope of study for this report -- the challenged sectors that have experienced a surge in both announced projects and realized investments following the introduction of the IRA.

This report views the following among the less-established sectors as likely ripe for nearer term investment:

1. Domestic manufacturing of components for wind, solar, batteries and critical metals
2. Clean Hydrogen
3. BESS
4. Clean Commercial Vehicles
5. Biofuels
6. SAFs

Figure 1. Selection process for Study



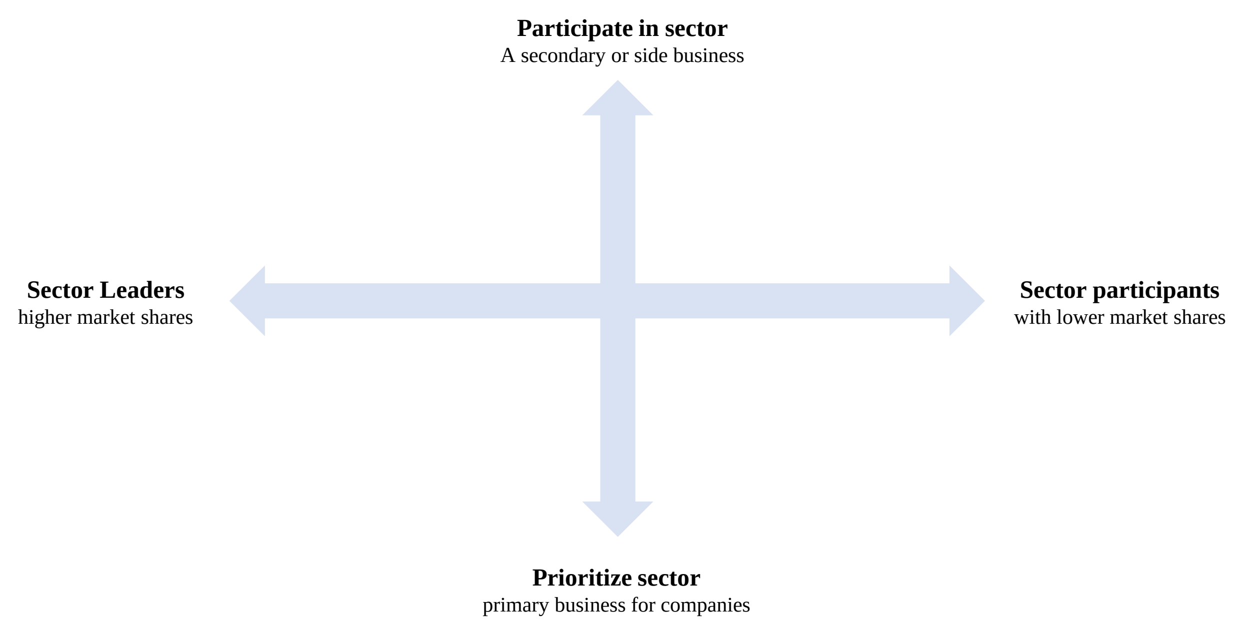
Source: Columbia SIPA

Each of these sectors is analyzed in greater detail in Part 2 of this report. These sector-analyses examine the current state and challenges facing each of the selected sectors pre-IRA, the specific IRA provisions relating to each sector, and recent announcements and forecasts of business activity in the sector. To help identify investment opportunities for Citi's clients, the report identifies publicly listed companies among the leading players in each sector and places them along a sorting matrix based on each player's relative leadership or market share and the sector's priority for the player.

Among the sectors examined in Part 2, the domestic manufacturing category appears to be the most promising for near-term investment opportunities. In as much as this sector is materially supported by overlapping incentives through the IRA, it contains a sizable number of market participants that are prominent publicly listed companies. The other five sectors examined in Part 2 also display notable levels of investment activity linked to the IRA with a broad range of investable players identified as sector leaders.

As an analytical tool for weighing the players within each sector, the participants each submarket have been placed within a sorting matrix with one axis based on their relative leadership or market share and the other axis ranking the business sector's relative priority for the market participants.

Figure 2. Likelihood-scope (L-S) matrix



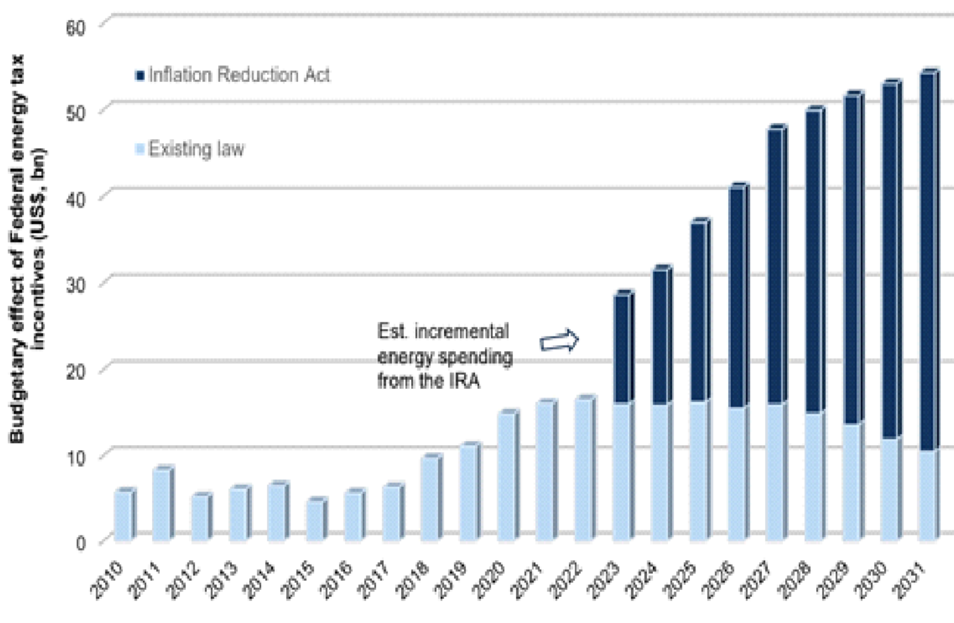
PART 1
Background and Context

1.1 Introduction

Since the 1980s, Congress has intermittently passed and allowed the expiration of tax incentives for renewable energy investment. Supporting investment in a broad range of carbon reducing activities were among the key elements of President Biden's original Build Back Better Agenda which ultimately proved to be too broad to obtain a senate majority. However, in the summer of 2022 the White House, Senate Majority Leader, Chuck Schumer and Senator Joe Manchin engaged over a reconciliation bill ultimately came out with a $891 billion deficit budget reform, which included some of the key Biden agenda items relating to climate change mitigation and green energy.[1]

The 2022 Inflation Reduction Act (IRA) was signed into law on August 16, 2022, and focuses on lowering healthcare costs, raising revenues through an alternative minimum tax for corporations and support for the Internal Revenue Service (IRS) to enhance tax collections, and most critically to mitigate climate change with expanded federal tax credits to motivate private investment in a range of commercial sectors that are key to reducing carbon emissions. It allocated $500 billion in spending and tax breaks to boost private investment in clean energy and related sectors focused on decarbonization challenges.

Figure 3. U.S. federal tax incentives on energy by 2031



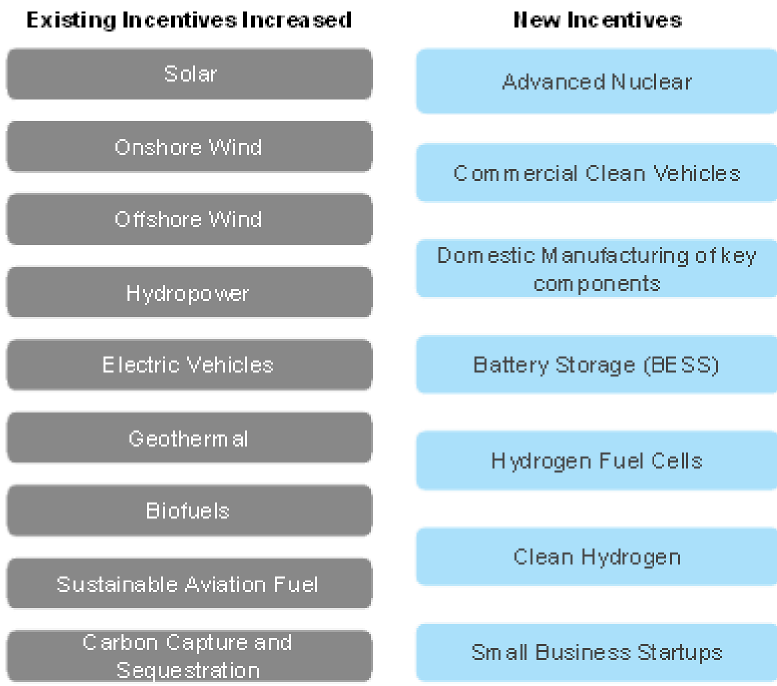
Source: U.S. Department of Treasury, Congressional Budget Office, Goldman Sachs Global Investment Research

[1] Chuck Schumer and Joe Manchin. "Joint Statement From Leader Schumer And Senator Manchin Announcing Agreement To Add The Inflation Reduction Act Of 2022 To The FY2022 Budget Reconciliation Bill And Vote In Senate Next Week," The Senate Democratic Caucus, 27 July 2022, www.democrats.senate.gov/newsroom/press-releases/senate-majority-leader-chuck-schumer. Accessed Oct. 2023

1.2 What is in the Inflation Reduction Act?

The IRA allocates approximately $394 billion for energy and climate initiatives over a period of 10 years. Approximately $265 billion of this comes in the form of tax credits, a portion of which encourage individuals to make purchases that increase the energy efficiency of their houses and modes of transportation.[2] More importantly for this study, a major portion of the tax credits are aimed at motivating businesses to invest in a range of at least sixteen industry sectors linked to mitigating climate change. Most of these sectors like renewable energy generation, electric vehicles (EVs) and low-emission fuels had already benefited from tax credit incentives prior to the IRA. In most cases these prior energy tax incentives have been extended and, in many cases, expanded by the IRA, increasing their total value and improving the terms of payment. Seven other sectors receive entirely new federal incentives which are described later in this report.

Figure 4. Sectors supported by IRA incentives



Source: The White House (2023)

The Act provides more extended time periods for availability of tax credits, and more paths for monetizing tax credits. There is a direct pay from the federal treasury entitlement for certain types of tax credits or certain types of investors. The IRA also allows tax credits to be sold to third parties as a monetization path; previous to the IRA, tax credits could only be claimed by owners of the eligible investment. The IRA further introduces a concept of linking the calculation of tax credit amounts, whether based on investment amounts or units of production to the carbon emissions intensity of the activity and whether targeted attributes are presented by the activity including

[2] McKinsey & Company. "The Inflation Reduction Act: Here's What's in It." McKinsey & Company, 24 Oct. 2022, www.mckinsey.com/industries/public-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it. Accessed Oct. 2023

union wage scales for workers, U.S. content in the equipment, and siting projects in favored communities.

Domestic Job Creation is one of the major themes of the Act. New and enhanced tax credits that especially reward investment in U.S. manufacturing, products with U.S. content, the payment of prevailing wages to workers, and siting investments in targeted areas (lower income, native reservations, energy communities) are among the Act's innovations targeting job-creation. This works by defining base tax credits for the various sectors which are increased if the eligible investment involves defined labor standards for workers mirroring what union contracts normally include. The tax credits can be increased further in some cases if the investment involved a defined amount of U.S. content, or if the investment is sited in a targeted community.

1.2.1 Incentives targeting Energy Communities

The provisions in the IRA regarding energy communities are viewed as a significant tool for incentivizing renewable energy investment in communities that historically relied on fossil fuel-related industries. These are locations that fall into three categories: brownfield, statistical area or coal closure category. For example, if the project is located in a low-income community or on Tribal land, a renewable energy project would be eligible for a 10 percent adder to the Investment Tax Credit (ITC). If a Production Tax Credit (PTC) were elected, the project would be entitled to a bonus credit of up to 10 percent (i.e., the PTC would be multiplied by 110 percent) if located in one of these favored sites.[3]

1.2.2 Incentives targeting stronger Labor Standards

By creating incentives for paying prevailing wages and utilizing qualified apprentices from registered apprenticeship programs in clean energy projects, the IRA aims to help expand well-paying union jobs and support proven pathways into the industry that allow workers to earn while they learn.

To receive increased credit under the Act, taxpayers will need to:

- Pay workers the local prevailing wage, defined in accordance with U.S. Department of Labor standards, for work on facility construction, as well as for alterations and repairs in a five-to-twelve-year period, depending on the credit, after a facility is placed in service[4]
- Hire a sufficient proportion of workers from registered apprenticeship programs, including hiring these qualified apprentices for at least 10 percent of the labor hours spent on facility construction, alteration, or repair work (rising to 12.5 percent for facilities where construction begins in 2023 and 15 percent in 2024 and later years)[5]

1.2.3 Incentives targeting supply chain security

Certain incentives in the IRA reflect the concern that the U.S. has become too dependent on imported equipment, particularly from China, and in particular lithium-ion batteries and the critical minerals to producing such equipment. There are several overlapping tax credits in the Act aimed

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[3] United States. A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action. January 2023, Version 2, www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.

[4] U.S. Department of the Treasury. "FACT SHEET: How the Inflation Reduction Act's Tax Incentives Are Ensuring All Americans Benefit from the Growth of the Clean Energy Economy." 20 Oct. 2023, home.treasury.gov/news/press-releases/jy1830. Accessed Nov. 2023

[5] Ibid

at promoting the production of batteries and their critical minerals in the U.S. As explained more fully in Part 2 of this report, certain tax credits are not available to purchasers of EVs unless specified targets for sourcing their critical minerals in the U.S. or among its Free Trade Agreement (FTA) partners are met.

1.2.4 New and Enhanced Credits

As explained in **Figure 4**, the Act doesn't just enhance existing tax credits for various sectors like solar and wind energy but also provides new credits for sectors that have been especially slow to become commercial (referred to as commercially challenged in this report). These sectors include clean hydrogen, carbon capture, battery storage, advanced nuclear (small-scale nuclear), clean fuels (biofuels), clean electricity, Sustainable Aviation Fuels (SAF), plus the domestic manufacturing of equipment, key components and critical minerals for the low carbon economy. Several of these heretofore commercially challenged sectors have been selected for close analysis and are detailed in Part 2 of this Report. Carbon Capture, Utilization and Storage (CCUS) and Advanced Nuclear are two sectors receiving substantial new support from the IRA as summarized below, but the investable opportunities for Citi's clients are still viewed as too distant for inclusion in Part 2.

Carbon Capture, Utilization and Storage: The Act provides critical updates to the 45Q tax credit, which was traditionally seen as a PTC style credit, to incentivize the use of CCUS. By expanding and enhancing 45Q, Congress has made the tax credit significantly more accessible to a broad array of investors and developers. This is a space where existing credits have been increased from $50/tonne to now $85/tonne. The credits range from $60 to $180 where $180/tonne is paid for Direct Air Capture (DAC) and permanent storage.

Advanced Nuclear: Although nuclear plants have an existing PTC of $1.8 cents per megawatt-hours (MWh) for the first 8 years when an "advanced nuclear power facility" begins service the IRA is accelerating the deployment of advanced small nuclear reactors, including small modular reactors. Advanced nuclear is different in size and cooling medium. The Act creates a zero emission PTC for certain existing nuclear power plants under Section 45U of the Code. Advanced nuclear are now eligible for technology-neutral PTC ($25/MWh) or 30 percent ITC (Placed into operation in 2025 or after) and brownfield sites/fossil energy communities get a 10 percent additional bonus catering to the aim of improving energy communities.

1.3 Key challenges for the IRA

The IRA was passed less than sixteen months prior to this report without any votes from Republican members in Congress. It has many critics and skeptics. Some have criticized the IRA as too costly. Stakeholders in Europe and Asia criticize the Act's US content elements as too protectionary. Some skeptics among experts and market observers point to project deployment goals, domestic content and critical minerals sourcing goals that they contend will be impossible to meet. It would be outside the scope of this report to evaluate this criticism. It is too soon to measure these issues, but a report of investment opportunities enabled by the IRA needs to acknowledge that there is opposition that could ripen into amendments or partial repeal in the future.

One of the key challenges with the Act is to pin down precisely how much will be spent as a result of the IRA. Cost estimates have continued to shift upward and now span a range of more than half a trillion dollars.[6]

Most of the spending comes in the form of tax credits that are uncapped in terms of aggregate volume, and those unlimited credits are designed to be rolled out over a 10-year span. There is no restriction on how many businesses or citizens can claim new tax incentives made available to support everything from the purchase of EVs to the production of green hydrogen and assembled-in-America batteries. The Act contains a range of climate and energy provisions previously estimated to cost $384.9 billion over 10 years (FY2022 – 2031) by the Penn Wharton Budget Model (PWBM).[7] Since that estimate, newer implementation details have emerged, and the fiscal year calendar has moved to start at FY2023. One such estimate by Wharton with Goldman Sachs has been revised to approximately $1 billion over the same period. John Bistline of the Electric Power Research Institute, along with colleagues, ran a model considering a wide variety of economic variables and highlighted that their modeling comparison really underscored is that a lot of the spending tends to happen close to the end of the 10-year budget window, so closer to 2030 which means we might not know what the costs are for a very long time.[8]

Figure 5 illustrates the dramatic pace of investment across many states in the many sectors supported by the IRA. It stands to reason that the volume of tax credits supporting these investments will grow at a dramatic pace.

In addition, the analysis this report provides in Part 2 details how small a share U.S. producers have in the production of equipment and components that are central to the energy transition. Key IRA provisions relate to diversifying supply chains for battery components and their critical minerals toward the U.S. and its FTA partners. A study from S&P Global Commodities Insights concludes that out of the three materials analyzed in the study, only lithium is likely to be sufficiently supplied to the U.S. under the IRA's domestic content requirements, given already-planned capacity additions in the U.S. and other FTA countries such as Chile, Canada and Australia, the study finds.[9] According to the research, the U.S.' growing reliance on imports in response to the growing demand for energy transition has brought fresh attention and urgency to issues including lengthy lead times and complex regulatory processes that impede the development of indigenous resources. Simon Moores, chief executive of Benchmark Mineral Intelligence[10], put it, “Considering it takes seven years to build a mine and refining plant but only 24 months to build

[6] “A Year into Biden’s Climate Agenda, the Price Tag Remains Mysterious.” Bloomberg.com, 16 Aug. 2023, www.bloomberg.com/news/articles/2023-08-16/total-cost-of-joe-biden-s-inflation-reduction-act-is-rising. Accessed Nov. 2023.

[7] Mariko Paulson. "Senate-Passed Inflation Reduction Act: Estimates of Budgetary and Macroeconomic Effects." Penn Wharton Budget Model, 12 Aug. 2022, budgetmodel.wharton.upenn.edu/issues/2022/8/12/senate-passed-inflation-reduction-act. Accessed Nov. 2023

[8] “A Year into Biden’s Climate Agenda, the Price Tag Remains Mysterious.” Bloomberg.com, 16 Aug. 2023, www.bloomberg.com/news/articles/2023-08-16/total-cost-of-joe-biden-s-inflation-reduction-act-is-rising. Accessed Nov. 2023.

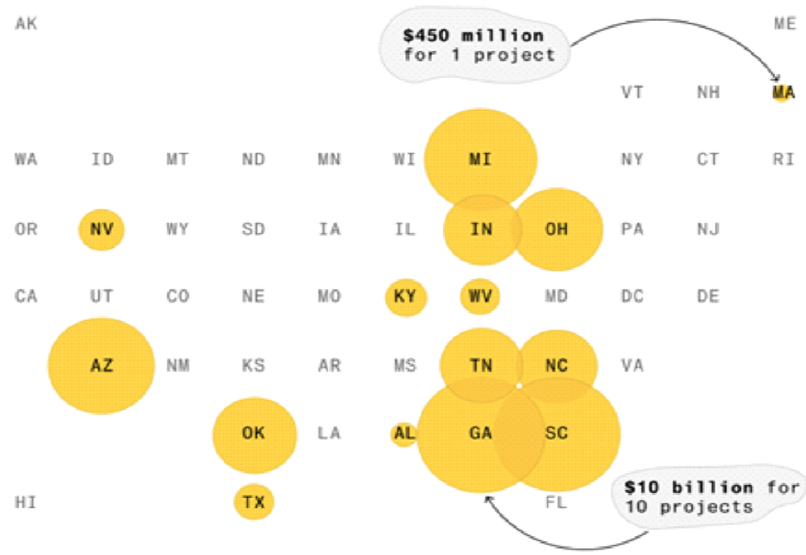
[9] S&P Global Market Intelligence. "Inflation Reduction Act: Impact on North America Metals and Minerals Market." Aug. 2023.

[10] Clara Denina, "Miners face supply chain overhaul to meet U.S. EV credit deadline," Reuters, August 11, 2022, https://www.reuters.com/markets/commodities/miners-face-supply-chain-overhaul-meet-us-ev-credit-deadline-2022-08-11/. Accessed Nov. 2023.

a battery plant, the best part of this decade is needed to establish an entirely new industry in the U.S."

In the short term, companies that increase their percentage of domestic inputs may be granted special waivers because it is unlikely that there will be enough local content available to meet these requirements over the next few years.

Figure 5. Investments by U.S. State since the passage of the IRA



Source: Bloomberg research

PART 2
Challenged Sectors

2.1 Domestic Manufacturing

As noted in Part 1 of this report, the objectives of IRA are numerous but at least three priorities are apparent: (i) the general policy to advance targeted industries that are part of the energy transition needed to mitigate climate change, (ii) to promote U.S. jobs generally with an emphasis on expanding domestic manufacturing related to the energy transition, and (iii) to address the U.S. security concerns that so much of the supply chain for the targeted industries is controlled by foreign production, China in particular.

Prior to the IRA, the decades-long U.S. practice of incenting investment in targeted sectors has been focused on *owners* and *buyers* of eligible facilities and equipment: ITC-type tax credits investors might take to net down their capital costs including equipment purchases to install windfarms, solar generation and other eligible facilities, or PTC-type tax credits based on the units of production such as MWhs of renewable electricity, or gallons of biofuels from the eligible plant and equipment -- a supplemental revenue stream that accelerates the investor's return. The *producers* of the necessary equipment or components for these eligible facilities experienced an *indirect* subsidy from these *buy-side* tax credits insofar as the credits for buyers enabled higher volumes of equipment sales, but investment in *equipment production* did not directly generate tax credits (excepting some narrow programs) prior to the IRA. While the IRA retains the longstanding focus of the U.S. tax policy to directly subsidize equipment buyers in most of the targeted sectors, the IRA also significantly adds two new *supply-side* tax credits directly supporting producers/manufacturers of targeted equipment; one investment-based, the other production-based.

2.1.1 IRA's new tax credits for manufacturing linked to climate mitigation

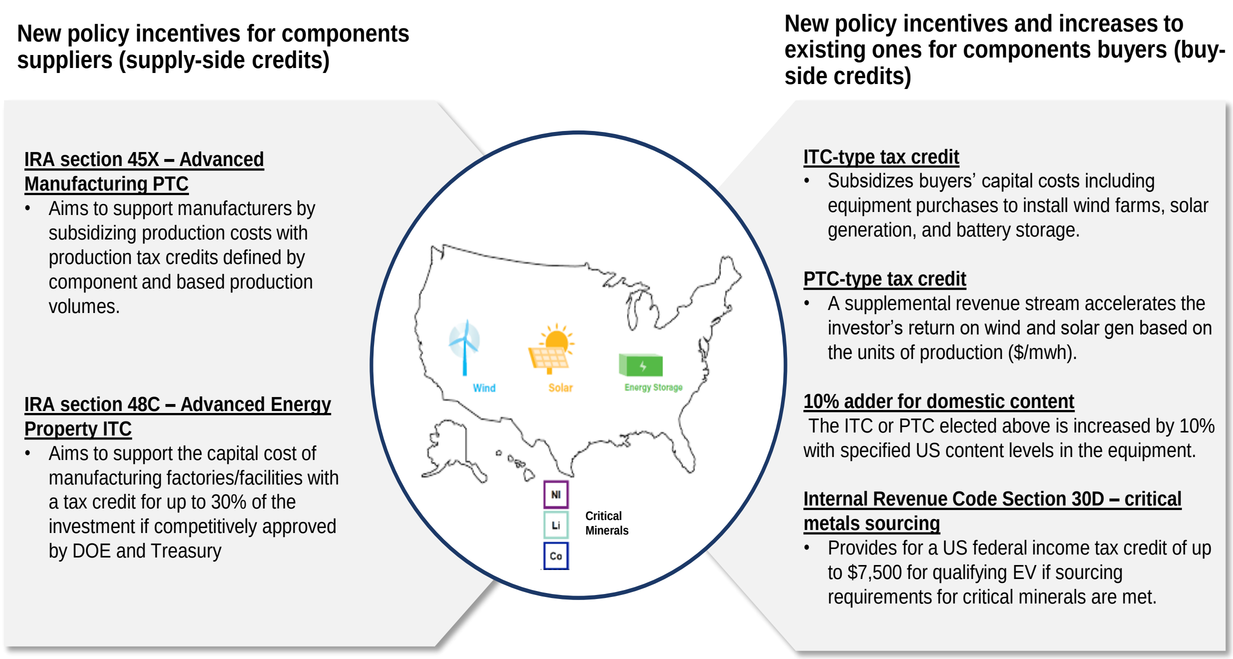
Advanced Energy Property ITC (section 48C): The IRA makes $10 billion in ITC-type tax credits available for Advanced Energy Property under section 48C of the Internal Revenue Code, reviving a one-time program from 2009. These tax credits are awarded through a competitive application process noted below. Advanced Energy Property has a broad definition that includes investment in manufacturing facilities for equipment involved in renewable energy production, fuels cells, grid modernization, carbon capture equipment, energy conservation technology, and hybrid vehicles and infrastructure. Eligible facilities may also be involved in refining low carbon or renewable energy fuels, or processing refining or recycling of "critical minerals" among other eligible activities. Projects to refurbish manufacturing facilities to achieve at least a 20 percent carbon emissions reduction may also qualify.

Advanced Energy Property tax credits of up to 30 percent of the investment cost for *approved facilities* may be available if prevailing wage requirements are met. If the facility is producing output that is also eligible or PTCs such as clean hydrogen or the various components favored by section 48X (explained in the subsections below), an election must be made between the 45C ITC or the applicable PTC – both cannot be claimed. However, for any particular investment to be eligible for this section 48C credit, specific approval by the two Federal agencies, the U.S. Treasury and the U.S. Department of Energy (DOE) through a competitive process for a share in the $10 billion award envelope is required. The DOE has already launched the approval process for up to $4 Billion of available tax credits; this began with applications responding to the Request for Proposal by the DOE in mid-2023.

Advanced Manufacturing (section 48X): The approval of the DOE and the U.S. Treasury is not required to claim the new PTC-type tax credits enabled by IRA under section 48X of the Internal

Revenue Code for the U.S. domestic manufacturing of eligible wind components, solar components, inverters, qualifying battery components, and applicable critical minerals. The tax code's new section 45X defines various specific tax credit amounts that manufacturers/producers within each of these favored subsectors may claim for the units or capacities produced for sale to third parties. These credits are available to support existing manufacturers, and not limited to new investments within a $10 billion envelope like the section 48C credits. *The section 48X credits may be the most impactful new tax code provision from the IRA in terms of this Report's objective to identify investment opportunities in previously challenged sectors enabled by the Act.* Each of these manufacturing subsectors is analyzed by the Report in greater detail below.

Figure 6. IRA support for both supply and demand



Source: Columbia SIPA

2.1.1.1 U.S. climate-linked manufacturing pre-IRA

Over the last decade, the U.S. has experienced a significant upswing in its commitment to clean energy. This has driven attention and investment into critical areas such as wind, solar, batteries, and related technologies. Over the last five years, the landscape of domestic clean energy projects has undergone a substantial transformation, marked not only by increased numbers of project deployments but also by a notable expansion in renewable generation capacity. The catalysts for this growth can be traced back to the introduction of ITC and PTC for wind and solar generation which, as noted earlier, subsidized owners of deployed renewables pre-IRA for their investment without regard to the U.S. domestic content. Illustrated by Figure 6, the sector has witnessed an impressive annual growth rate of 15 percent over the past half-decade[11]. The last three years, in particular, have seen remarkable net additions to this capacity. Incentives in the U.S. tax code have played a pivotal role in this trajectory, with 272 new clean energy projects announced, attracting a substantial $278 billion in investments.

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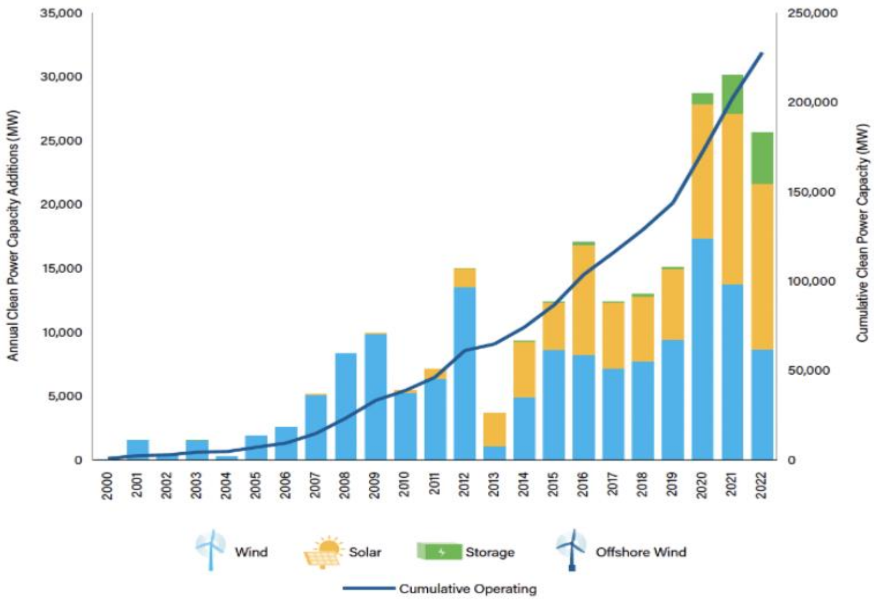
[11] "2022 Marks Third-Highest Year for U.S. Utility-Scale Solar, Wind, and Storage Installations," American Clean Power Association, May 22, 2023, https://cleanpower.org/news/market-report-2022/. Accessed Oct. 2023

However, while the U.S. has enjoyed domestic success in clean energy endeavors, a significant disparity exists regarding global market share in clean energy component manufacturing. The majority of components for wind, solar, and batteries are currently supplied by China, leaving U.S. suppliers with a comparatively smaller share, as depicted in **Figure 7** – on average less than 15 percent of global supply is provided by domestic manufacturers across sectors, whose presence is particularly week regarding specific components including photovoltaic (PV) wafers, wind blades, and battery anodes.

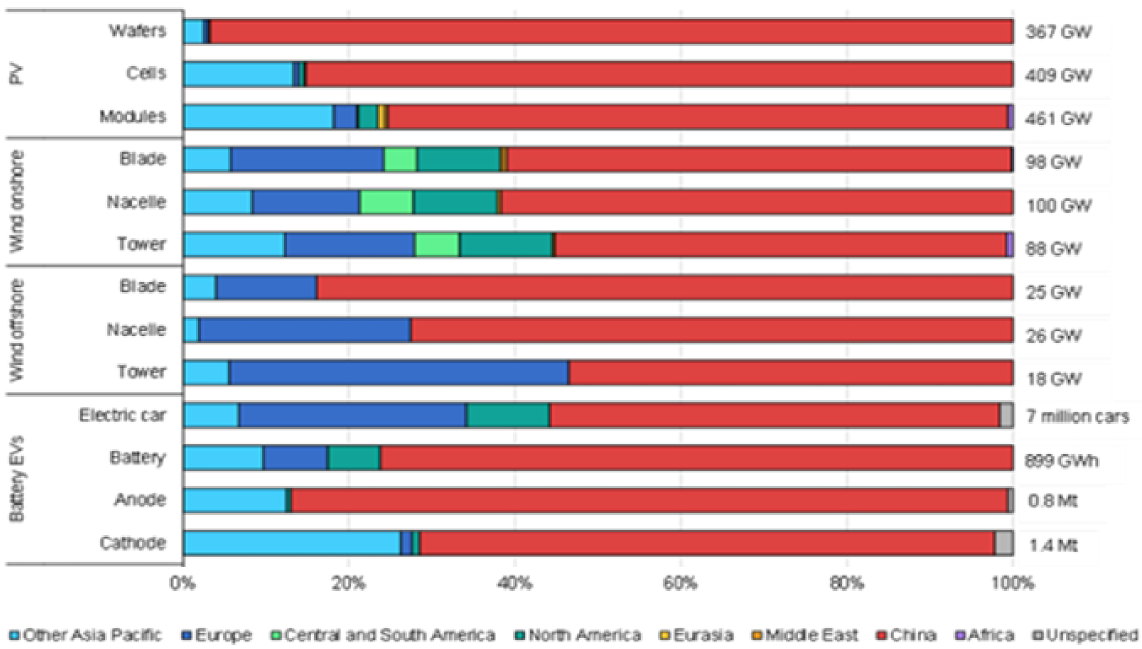
Figure 7. U.S. annual and cumulative utility-scale clean power capacity growth



Source: American Clean Power Association

The bars in **Figure 8** well illustrate how dominant China has become in the supply of equipment linked to the deployment of wind and solar generation along with EVs and batteries. The small share supplied by North American sources is also evident. The manufacture of these equipment types and components in the U.S. has clearly been a challenged sector. The introduction of the Advanced Manufacturing Production Credit under the IRA presents a transformative solution. The following subsections of this Report analyzes in greater detail how IRA, especially through the newly introduced 45X PTC, aims to support the development of a robust domestic supply chain for wind, solar and battery component manufacture, and critical minerals production.

Figure 8. Regional shares of manufacturing capacity for selected mass-manufactured clean energy technologies and components, 2021



Source: International Energy Agency

2.1.2 Advanced manufacturing production for wind components

While renewable wind energy is now an established part of the global energy industry, the advanced manufacturing of wind turbines remains challenging in the U.S. for multiple reasons. Carbon fiber, glass fiber, and balsa wood, which make up the greatest volume of materials used in the manufacture of wind turbine blades, nacelles, and towers, are already becoming scarcer due to the expansion of the wind industry and the use of these materials in other sectors.[12] Among the rare earth metals and minerals critical to the manufacturing process, the U.S. wind industry is already using more nickel than can be produced domestically.[13] China alone makes up 44 percent of total global wind capacity, with Germany and the U.K. second and third, putting the U.S. at a global disadvantage when it comes to sourcing and shipment.[14] Having failed to develop a domestic manufacturing base, U.S. wind projects are bidding against far more established buyers on the international market.

Before the IRA's implementation, the cost of components for both wind and solar generation was already experiencing upward pressure due to supply chain issues, tariffs, and interest rate increases. Tariffs were first imposed starting in 2019 under the Trump administration, particularly on solar components. The U.S. has maintained anti-dumping duties on Chinese-made solar products for over a decade, in response to findings that Chinese companies benefited from unfair

[12] Materials Used in U.S. Wind Energy Technologies: Quantities and Availability for Two Future Scenarios," National Renewable Energy Laboratory et al., August 2023.
[13] Ibid
[14] "IRA at 1: US boost to offshore wind imperiled by struggling projects," S&P Global Market Intelligence, August 15, 2023, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/ira-at-1-us-boost-to-offshore-wind-imperiled-by-struggling-project. Accessed Sept. 2023.

government subsidies, enabling them to keep prices artificially low.[15] This situation has led to an increase in the overall cost of U.S.-bound solar products. The tariffs, therefore, represent a significant factor in the rising costs of solar components.

The onset of the COVID-19 pandemic in 2020 triggered widespread industrial slowdowns, leading to significant supply chain disruptions and project delays in the wind and solar sectors. These disruptions were further compounded by worker restrictions and delays in component shipments from China and other regions, causing some wind developers to delay or cancel projects.[16] The supply chain disruptions became significant in 2021 following the global lockdown due to low inventories and delays, leading to scarcity pricing. The start of the war in Ukraine in 2022 also intensified logistics and supply chain challenges, further straining the industry.[17] This created a domino effect, increasing manufacturing costs and, subsequently, the prices of wind and solar components.

The interest rate increases in late 2022 and 2023 further complicated the situation. Higher interest rates particularly impacted project developers and buyers of wind energy equipment, as they now face higher costs to finance their projects, which could lead to higher prices for end-users. The increase in interest rates played a critical role in pushing up the levelized costs of energy (LCOEs) for wind and utility-scale solar projects, as it disproportionately impacts sectors like offshore wind, which experienced a staggering 50 percent rise in its LCOE from 2021 to 2023.[18]

Some market observers and participants believe the IRA adds to the cost pressures. The U.S. content requirements in the IRA could create higher demand for domestically produced components, potentially putting further upward pressure on pricing. Market participants interviewed for this study opined that the IRA impacts the market by promoting domestic manufacturing, leading to a spike in demand and a concurrent reduction in supply. Prices have surged for panels unaffected by tariffs and those without Chinese-made polysilicon. Market participants interviewed confirmed that the demand for turbines and other wind components from top-quality manufacturers like Vestas and GE has increased, increasing equipment prices. Wind projects, generally yielding lower profits per MWh, now require large-scale developments to be cost-effective.

The new credits were meant to spur investments that could make up for gaps in the wind economy, as identified in reports conducted by the National Renewable Energy Laboratory (NREL) and the DOE Office of Energy Efficiency and Renewable Energy.[19]

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[15] Nichola Groom, "US places tariffs on some big solar companies for dodging China duties," Reuters, August 18, 2023, https://www.reuters.com/sustainability/us-slaps-tariffs-some-big-solar-companies-dodging-china-duties-2023-08-18/. Accessed Nov. 2023.

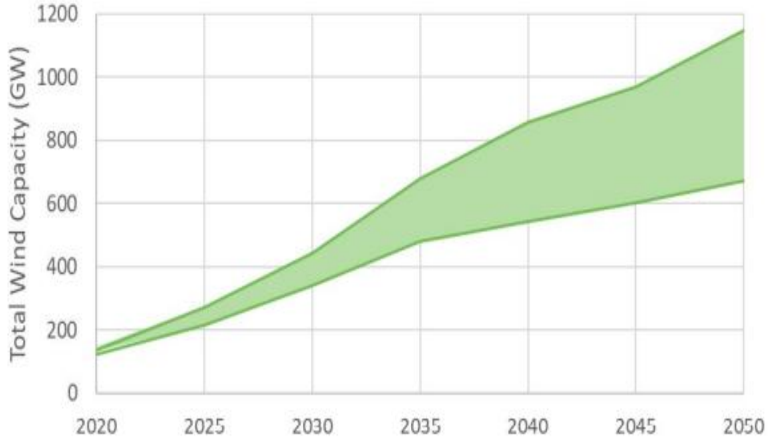
[16] Nina Chestney and Susanna Twidale, "Explainer: Why the offshore wind power industry has hit turbulence," Reuters, September 8, 2023, https://www.reuters.com/business/energy/why-wind-power-industry-has-hit-turbulence-2023-06-26/. Accessed Nov. 2023

[17] Ibid

[18] Marlene Motyka et al., "2024 renewable energy industry outlook," Deloitte Insights, https://www2.deloitte.com/us/en/insights/industry/renewable-energy/renewable-energy-industry-outlook.html. Accessed Nov. 2023

[19] U.S. Department of Energy, "Wind Energy Supply Chain Report - Final," February 24, 2022.Accessed Nov. 2023.

Figure 9. U.S. wind capacity under 2050 net-zero scenarios



Source: the U.S. Department of Energy

The Biden administration has had a goal for offshore wind development of generating 30 gigawatts (GW) of offshore wind energy by 2030, tripling the current total domestic wind capacity.[20] On top of the material cost increases affecting renewables deployment generally, supply chain issues are particularly impacting offshore wind projects include the logistics of transporting equipment and materials, the need for specialized ports and a lack of suitably trained workers.[21]

Industry experts estimate that 30 GW of annual domestic generation capacity is needed by 2030. According to the NREL, the country would need an additional 34 manufacturing facilities to meet this generation capacity goal.[22]

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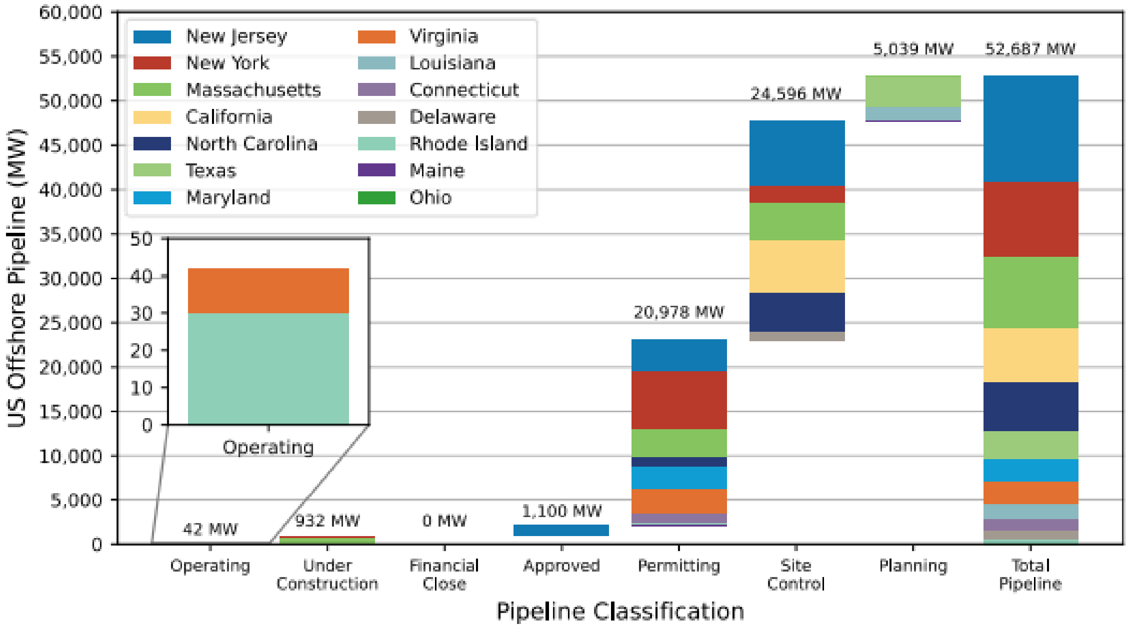
[20] "FACT SHEET: Biden-Harris Administration Continues to Advance American Offshore Wind Opportunities," The White House, March 29, 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/03/29/fact-sheet-biden-harris-administration-continues-to-advance-american-offshore-wind-opportunities/. Accessed Nov. 2023

[21] U.S. Department of Energy, "Wind Energy Supply Chain Report - Final," February 24, 2022.Accessed Nov. 2023

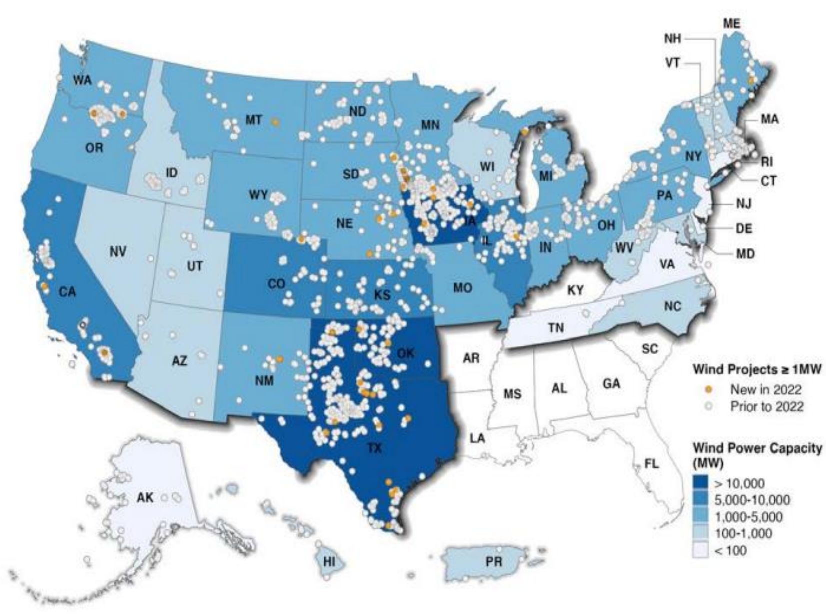
[22] "Supply Chain Road Map for Offshore Wind Energy in the United States," National Renewable Energy Laboratory, https://www.nrel.gov/wind/offshore-supply-chain-road-map.html. Accessed Nov. 2023.

Figure 10. U.S. project pipeline classification by status



Source: the U.S. Department of Energy

Figure 11. Location of wind power development in the U.S.



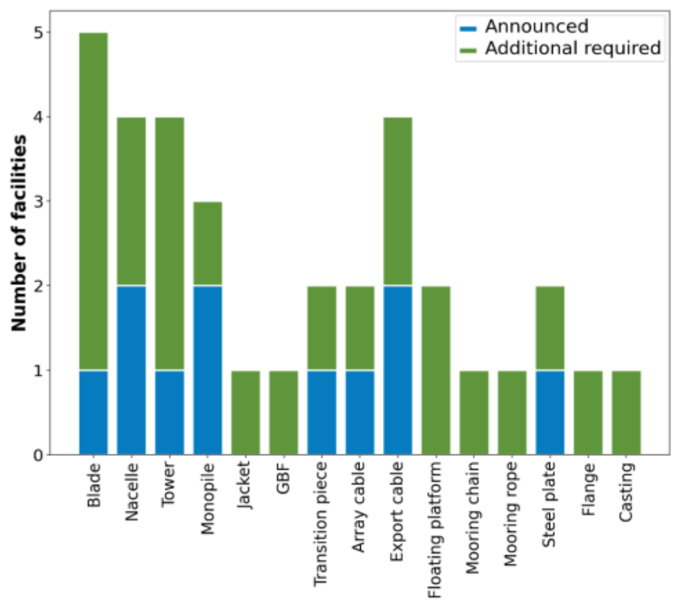
Source: the U.S. Department of Energy

2.1.2.1 Section 45X-related incentives for wind components

The IRA subsidizes the production of equipment used in the wind generation sectors through PTCs based on units of equipment produced for sale, or an ITC based on the costs of a wind equipment manufacturing facility. The IRA also contains material buy-side incentives that will increase demand for U.S.-produced wind equipment. The tax credits that a developer/owner may be entitled to take for deploying a wind generation project are materially increased if the project has met specified required levels of U.S. content.

The PTC for producing wind components is outlined in Section 45X of the IRA, which details the qualifying wind generation equipment and the amounts of tax credit entitlement as a function of total rated capacity in watts, in addition to credits for the sale of offshore wind vessels.[23] After 2030, the PTC will be reduced by 25 percent each year and eliminated after 2032, expecting the U.S. domestic supply chain to develop enough to become self-sustaining.

Figure 12. The number of manufacturing facilities required to develop domestic offshore wind energy supply chain



Source: National Renewable Energy Laboratory

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[23] "Title 26, U.S. Code," U.S. Census Bureau, https://www.census.gov/history/www/reference/privacy_confidentiality/title_26_us_code_1.html. Accessed Nov. 2023.

Table 1. IRA policy incentives for manufacture of wind components

Wind Components	Tax Credit
Component for Off-Shore Wind Vessel	10% of the sale price of the vessel
Component for On-Shore Wind Vessel	Pre-determined amount for type of component x total rated capacity (/W) of the completed wind turbine
Blade	$0.02 x total rated capacity
Nacelle	$0.05 x total rated capacity
Tower	$0.03 x total rated capacity
Offshore Wind Fixed Platform	$0.02 x total rated capacity
Offshore Wind Floating Platform	$0.04 x total rated capacity

Source: Bloomberg

As noted previously, Section 48C of the IRA provides for an ITC equal to 30 percent of the investment for a range of Advanced Energy Property competitively awarded in a process controlled by the DOE and the IRS, with up to $10 billion in total funds available for this program,[24] and a limit of up to $2.3 billion for any single project.[25] Facilities involved in manufacturing wind components can be eligible for this section 48C ITC. Qualifying facilities may be involved in manufacturing or recycling equipment. Facilities approved for the section 45C ITC also cannot take the PTC's in 45X on equipment produced. A look at recent announcements and key players in the industry will provide a clearer picture of how the IRA's provisions have impacted investment thus far.

2.1.2.2 Recent announcements and key players for wind components

From the passage of the IRA to the present, there has been a marked increase in investment, with at least eleven new wind manufacturing facilities announced since August 2022 and additional wind farms being announced this year.

TPI Composites, which manufactures wind turbine blades, tools, and other equipment, saw its net sales decrease in 2023 even as its unit sales of turbine parts increased slightly.[26] Although the company sold more wind blades in 2023 than in 2022, an increase in material costs (particularly resin and carbon fiber) and logistical problems, such as spillover effects from a plant closure and

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[24] Ibid.

[25] "Title 26, U.S. Code," U.S. Census Bureau, https://www.census.gov/history/www/reference/privacy_confidentiality/title_26_us_code_1.html. Accessed Nov. 2023.

[26] "TPI Composites, Inc. Announces Third Quarter 2023 Earnings Results." TPI Composites, Inc. November 2, 2023. https://ir.tpicomposites.com/websites/tpicomposites/English/2120/us-press-release.html?airportNewsID=e183aaab-5097-49ef-9d4e-c332bad00b58. Accessed Nov. 2023.

product redesign in 2022, offset this increase.[27] On top of this, service contracts decreased in value as existing orders transitioned to repair and inspection.[28]

Vestas is a leading manufacturer of wind turbines with two existing production facilities in the U.S. and has announced multiple new contracts in 2023.[29] By August 2023, it had announced at least four orders totaling 446 megawatt (MW) capacity from 72 of its V120 turbines and 64 of its V150 model.[30] On top of that, in September 2023, the company announced it secured another 90 MW repowering order, including a multi-year service contract to begin in 2024, with all of these combining to make an eight percent increase over the previous year.[31]

General Electric (GE) just recently announced the first assembly of its Vernova 6.1-158 onshore wind turbine to be manufactured in its newly expanded New York facility.[32] In May 2023, the company announced that it would be expanding the facility, which already produced steam turbines and generators, to begin manufacturing wind turbines as a direct result of the tax credits offered by the IRA.[33] Once the wind turbine production lines are at full capacity, GE expects to employ people to produce over 100 turbines by the end of 2024.[34] GE is also already supplying 62 of its Haliade-X turbines for the Vineyard Wind 1 project, a utility-scale wind farm constructed off the Massachusetts coast.[35] GE's investment in the wind sector near the end of 2023 is a reversal from its position the previous year when it announced that it would reduce the size of its wind-related workforce.[36] At the same time, GE has announced that it intends to expand its GE Vernova facility in the second quarter of next year.[37] GE Vernova manufactures onshore wind turbines, machine heads, hubs, and drive trains. The passage of the IRA has fueled market demand, which drives expansion. GE plans to hire 200 more employees at this manufacturing plant in the coming year. The IRA has ushered in a new era of supply-side growth. Over time, this will likely lead to increased production and lower costs, enabling wind developers to buy domestic components and green industrial products.

Siemens Energy AG is one of the longstanding leaders in the supply of wind generation turbines, but it recently revealed serious issues with its Siemens Gamesa division's manufacturing capability and future viability.[38] On November 15th, 2023, Siemens Energy announced that it would be scaling back its production of wind turbines after repeated manufacturing problems, including

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27 Ibid.

28 Ibid.

29 Marina Markosyan, "Vestas Signs 158-MW Repowering Contract in US," Renewables Now, renewablesnow.com/news/vestas-signs-158-mw-repowering-contract-in-us-831912/. Accessed 19 Nov. 2023.

30 Ibid.

31 "Vestas secures 90 MW repowering order in the USA," Vestas, 29 Sept. 2023. www.vestas.com/en/media/company-news/2023/vestas-secures-90-mw-repowering-order-in-the-usa-c3845358. Accessed 19 Nov. 2023

32 Sean Wolf, "First Wind Turbine Produced at GE Vernova's New York Facility," Power Engineering International, 17 Nov. 2023. www.powerengineeringint.com/renewables/wind/first-wind-turbine-produced-at-ge-vernovas-new-york-facility/. Accessed Nov. 2023

33 Ibid.

34 Ibid.

35 "Vineyard Wind 1," Vineyard Wind. www.vineyardwind.com/vineyardwind-1. Accessed 18 Nov. 2023

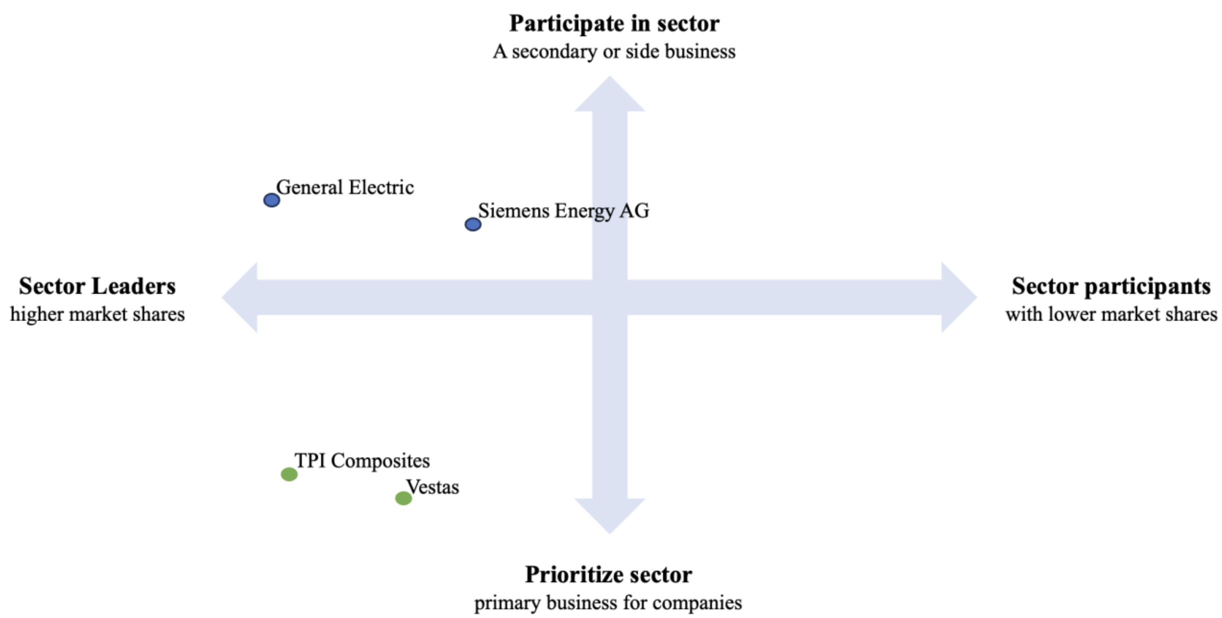
36 Wolf, "First Wind Turbine Produced at GE Vernova's New York Facility."

37 Ibid.

38 Ibid; Christoph Steitz and Alexander Hubner, "Siemens Energy Reviews Wind Unit Set-up after $5 Billion Loss." Reuters, Thomson Reuters, 15 Nov. 2023. www.reuters.com/business/energy/siemens-energy-reviews-structure-wind-unit-after-5-bln-loss-2023-11-15/.

defects in blades and bearings.[39] With a comprehensive restructuring strategy in response to a significant net loss of €4.6 billion, Siemens Energy management has reconfirmed its commitment to the energy transition.[40] Its extensive order backlog, exceeding €110 billion, and government support, including a €7.5 billion credit guarantee, position Siemens Energy as a crucial contributor to renewable energy's future.[41]

Figure 13. Matrix evaluation of key wind component players



Source: Columbia SIPA

2.1.3 Advanced manufacturing production for solar components

Over the last ten years, solar power has transitioned from an emerging, specialized technology to a well-established player in the energy sector. It is projected that by 2035, solar energy generation could contribute to 40 percent or more of the U.S. electricity demand.[42] Yet, the U.S. has so far held a very small share in the production of solar generation equipment while China has the largest shares on most categories.

The assembly of components required for the installation of a photovoltaic power system involves a global supply chain. PV modules, also known as panels, consist of cells utilizing various technologies. In the U.S., two predominant types of solar modules are utilized: crystalline silicon (c-Si) modules, constituting 84 percent of the market, and cadmium telluride (CdTe) modules, making up 16 percent of the market. Mounting structures, or racking, are essential for both module types to offer mechanical support, and these structures can be designed to track the sun. Inverters

[39] Ibid.
[40] Ibid.
[41] Ibid.
[42] "Solar Futures Study." U.S. Department of Energy, Sept. 2021.

to convert the electrical output from PV module in direct current (DC) to alternating current (AC) are common elements in a solar array.

Figure 14. The solar photovoltaics supply chain

Source: U.S. Department of Energy

Polysilicon Refining

The supply chain for c-Si modules begins with the refining of high-purity polycrystalline silicon (polysilicon). Metallurgical-grade silicon (MGS), derived from high-grade quartz, serves as the primary input material for polysilicon. Approximately 12 percent of the world's MGS is refined to produce high-purity polysilicon for the solar supply chain. Polysilicon undergoes melting to form monocrystalline silicon ingots, subsequently sliced into thin silicon wafers. These wafers are then processed to create solar cells, which are interconnected and enclosed between glass and plastic sheets to fabricate c-Si modules. China presently holds approximately 70 percent [43] of the global MGS production capacity.

Ingots/Wafers

About 97 percent of the global production of silicon wafers takes place in China. These wafers are transported from China and transformed into solar cells. Notably, approximately 75 percent of the silicon solar cells integrated into modules installed in the U.S. originate from Chinese subsidiaries situated in three Southeast Asian countries: Vietnam, Malaysia, and Thailand. So far, the U.S. does not engage in active c-Si ingot, wafer, or cell production.

Cell Fabrication

In 2020, the top 10 cell manufacturers accounted for 68 percent of the total production, all of these of Chinese origin except Hanwha Q cells of Korea.[44] Although this indicates a level of market concentration, it is notably less pronounced compared to earlier stages in the manufacturing process before the production of cells. The majority of U.S. cell manufacturing has been spearheaded by six companies, among which only three—SolarWorld, Suniva, and Tesla—managed to achieve capacities surpassing 400 MWdc. Two of these six companies, Evergreen and Suniva ended up in bankruptcy, while Silicor Materials, Tesla, and Mission Solar opted to cease their U.S. cell manufacturing operations. SolarWorld was sold to SunPower, which briefly operated the facility in Oregon until its closure in 2021. The U.S. manufacturers complained they were not able to compete at price levels comparable to imported cells and modules notwithstanding the tariff impositions. By the end of 2020, there was no domestic production of PV cells in the U.S.

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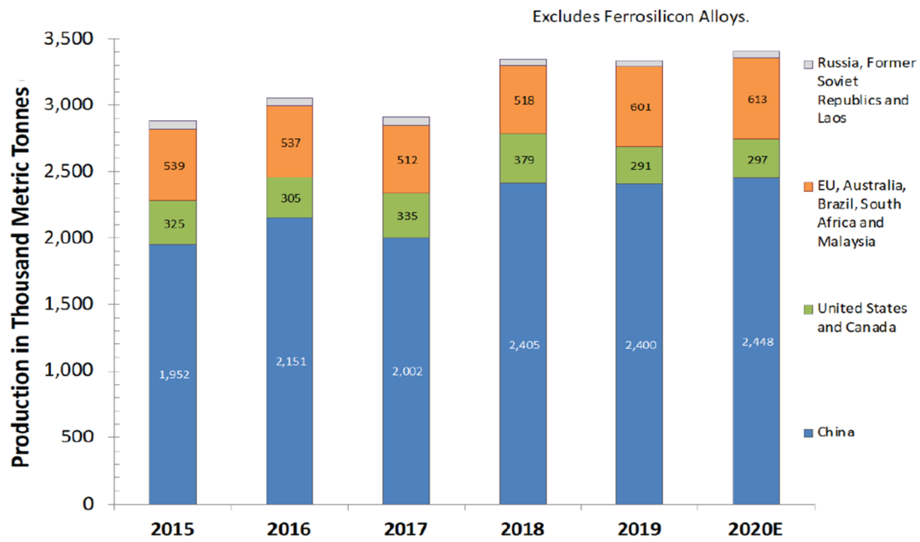
[43] "Solar Photovoltaics Supply Chain Deep Dive Assessment." U.S. Department of Energy, Feb. 2022.

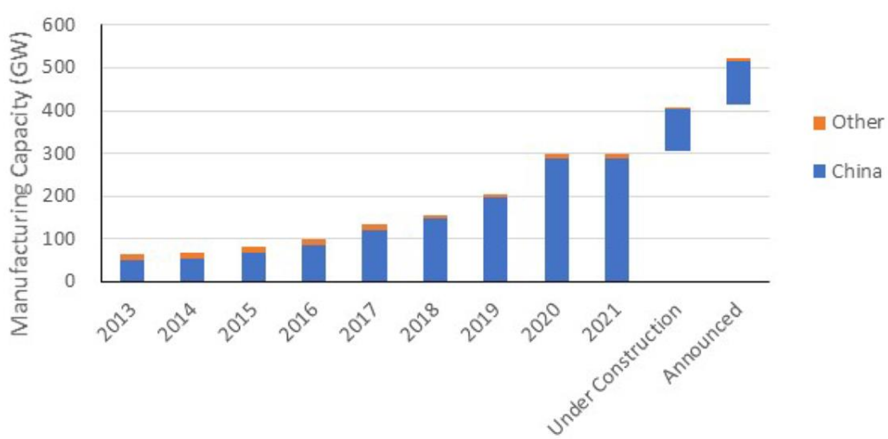
[44] Ibid

Figure 15. Principal locations of MGS production



Source: USGS, British Geological Survey

Figure 16. Wafer manufacturing capacity in China vs other locations



Source: BloombergNEF (2021)

Module Assembly

A significant 77 percent of module manufacturing is concentrated in China. Module manufacturing capacity outside of China ranges from just 90 to 100 GWdc.[45] While a considerable portion is situated in Asia, there are notable levels of module manufacturing capacity strategically positioned near regions with substantial PV demand, including Europe and the U.S. The process of module assembly involves the electrical connection of cells into strings, organizing parallel cell strings into an array, connecting these strings electrically using metallic ribbons, mounting the array onto a layer of encapsulant positioned on top of either a sheet of glass or backsheet, and finally,

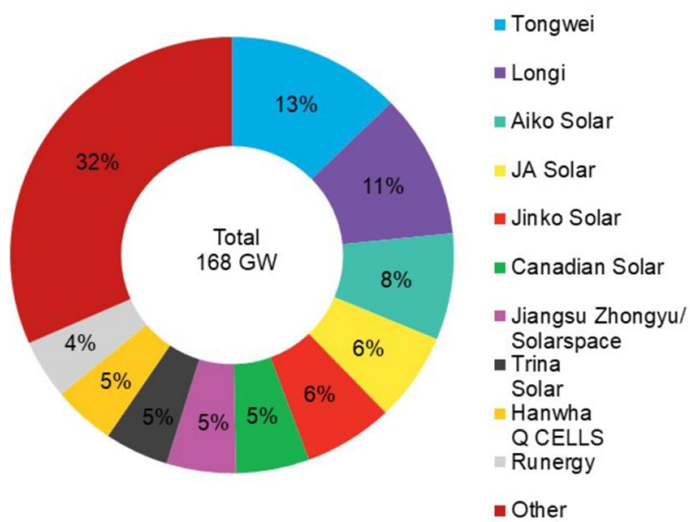
[45] Ibid

laminating another sheet of encapsulant and front glass onto the entire assembly. Module manufacturing is frequently situated close to wafer and cell manufacturing, primarily to leverage synergies in the manufacturing process, streamline equipment and land procurement, capitalize on captive demand, and benefit from economies of scale.

Mounting Structure

PV mounting structures serve the crucial role of securing PV panels in position, protecting them against wind forces, and ideally facilitating air circulation beneath the panels to maintain lower temperatures. This design aims to enhance the efficiency of the cells by promoting optimal operating conditions. For single-axis tracking ground-mount systems which are used for over 70 percent of utility-scale PV capacity, the two largest tracker vendors, both globally and within the U.S., are the U.S. companies NEXTracker and Array Technologies. Together, they accounted for 70 percent of the U.S. tracker shipments and 46 percent of global tracker shipments in 2020.[46] However, they still heavily rely on international suppliers for aluminum and steel.

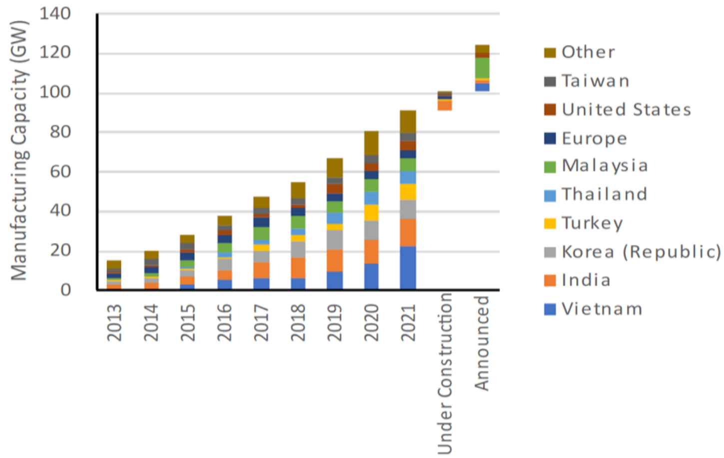
Figure 17. Cell production by manufacturer, 2020



Source: BloombergNEF (2021)

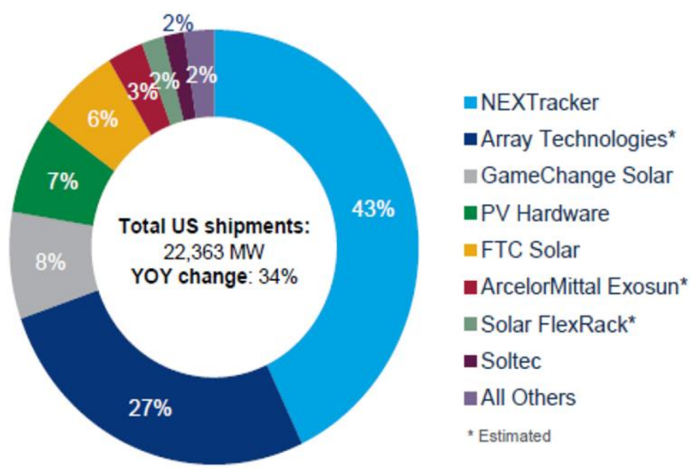
[46] Anne Fischer. "A New Era of Made-in-USA Solar." *Pv Magazine USA*, 16 Sept. 2022, pv-magazine-usa.com/2022/09/19/the-rise-of-made-in-usa-solar. Accessed Nov. 2023

Figure 18. Module manufacturing capacity outside of China



Source: BloombergNEF (2021)

Figure 19. U.S. PV tracker market share rankings by shipment, 2020



Source: Wood Mackenzie Power & Renewables (2021)

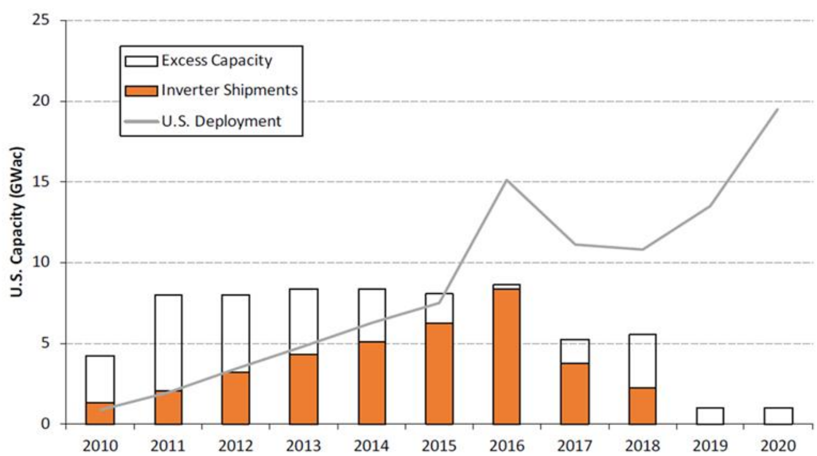
Inverters

Inverters serve as the central power electronics equipment in PV systems, tasked with converting the DC energy generated by PV modules into AC energy, which can be utilized by the electric grid. Components including semiconductor power electronics, the power blocks, and passive components are commonly produced in different countries through the global supply chain and are ultimately assembled into inverters. Despite the large presence of U.S., European, and Japanese semiconductor power electronics companies, a significant portion of the manufacturing is done in China and other regions of Asia. Over the period from 2012 to 2017, the American presence in this sector decreased from 10 percent to eight percent of the market, while China and the Asia Pacific region saw an increase, accounting for 54 percent to 58 percent of the market. In 2020, 185

GWac of PV inverters were manufactured globally, with 121 GWac, or 66 percent, from companies headquartered in China.[47]

The U.S. inverter manufacturing capacity experienced a decline in the second half of 2016, primarily attributed to the ongoing decrease in prices for utility-scale inverters. Inverters are still being manufactured in the U.S., predominantly by foreign-owned firms, but the production levels are notably lower compared to previous years. Concurrently, the demand for inverters in the U.S. has continued to rise, resulting in a decrease in the percentage of installed content sourced from domestic producers.

Figure 20. U.S. inverter production, manufacturing capacity, and system deployment



Source: Wood Mackenzie & SEIA 2021

2.1.3.1 Section 45X-related incentives for solar components

As with the manufacture of other targeted equipment, IRA directly subsidizes the producers of solar components with tax credits that may be elected between two sections. A section 48C Advanced Energy Property ITC explained earlier in this report may be elected based on the cost of a new or refurbished facility to manufacture solar equipment if approved through an application process with the DOE and the IRS. Alternatively, solar equipment manufacturers can take advantage of PTC's based on their production volumes under section 45X of solar components listed in **Table 2**. The phase-out of 45X PTC is the same as wind components, beginning in 2030 with a cut of 25 percent of full unit credit per annum and no credit after 2032.

In addition to these direct supply-side incentives to solar equipment manufacturers, the IRA introduced indirect buy-side incentives for U.S.-sourced solar equipment. As explained already in the context of wind components, the ITCs or PTCs that have been available to for renewables generation projects for decades can be increased post-IRA by 10 percent "adders" if specified U.S. domestic content requirements are met. These adders are intended by IRA policy makers to increase demand for solar components manufactured in the U.S.

[47] "Solar Photovoltaics Supply Chain Deep Dive Assessment." U.S. Department of Energy, Feb. 2022.

Table 2. IRA policy incentives for manufacture of solar components (left) and inverters (right)

Solar Components	Tax Credit
Thin film PV Cell	$0.04 x capacity /W (DC)
Crystalline PV Cell	<$0.04 x capacity /W (DC)
PV Wafer	$12/m^2
Solar Grade Polysilicon	$3/kg
Polymeric Backsheet	$0.40/m^2
Solar Module	$0.07 x capacity /W (DC)
Torque Tube	$0.87/kg
Structural Fastener	$2.28/kg

Inverters	Tax Credit
Inverter	Pre-determined amount for type of inverter x capacity of inverter
Central Inverter	$0.0025 x capacity
Utility Inverter	$0.015 x capacity
Commercial Inverter	$0.02 x capacity

Source: H.R. 5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022 | Congress.gov | Library of Congress.

Table 3. Tax credit for eligible U.S. produced components by year sold

2023-2029	2030	2031	2032	After 2032
Full 45X MPTC unit credit	75% of the full unit credit	50% of the full unit credit	25% of the full unit credit	no credit

Source: H.R. 5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022 | Congress.gov | Library of Congress.

2.1.3.2 Recent announcements and key players for solar components

There have been billions of dollars of IRA-related announcements for new domestic solar manufacturing capacity, with many billions more on the way. The IRA appears to have sparked a wave of announcements for new manufacturing capacity, including plans for 47 GW of new modules, over 16 GW of cells, and over 16 GW of ingots and wafers. Additionally, there are indications of more than 20,000 tons of annual domestic polysilicon capacity coming back online, and a multitude of new investments in tracker and racking capacity. 52 new solar manufacturing facilities have been announced since August 2022. The expectation is for substantial exponential growth across all these sectors. Solar Energy Industries Association (SEIA) estimates that by 2030 the IRA will lead to the creation of 115,000 jobs in solar and storage manufacturing alone, and more than 507,000 jobs across the entire industry.[48]

Notable investments include ***First Solar***'s 3.5 GW thin-film PV factory in Alabama, and other four constructions in progress.[49] First Solar is the leading solar module manufacturer and the only U.S.-

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[48] "American Solar and Storage Manufacturing Renaissance." Solar Energy Industries Association, Mar. 2023.

[49] Pippa Stevens. "First Solar Announces New U.S. Panel Factory Following the Inflation Reduction Act." *CNBC*, CNBC, 31 Aug. 2022, www.cnbc.com/2022/08/30/first-solar-to-build-new-panel-factory-following-inflation-reduction-act.html. Accessed Nov. 2023.

headquartered manufacturer among the world's ten largest solar manufacturers. First Solar has the Western Hemisphere's largest solar manufacturing footprint in Ohio, with a third factory set to come online in late 2023. The company expects to have a global annual manufacturing capacity of over 20 GW by 2025.

Solar module supplier ***Canadian Solar*** announced a new manufacturing facility of $250 million investment located in Texas, marking the company's first U.S. manufacturing facility. The manufacturing plant is designed with a planned output of 20,000 modules per day, translating to a total annual production capacity of 5 GW.[50] Canadian Solar has over 26 manufacturing facilities in Asia and Americas with an expected module capacity of 61 GW.

Citing the IRA's incentives, Korea's ***Hanwa QCells***, which already operates panel manufacturing in the US, just announced it would invest $2.5 Billion in a new panel manufacturing facility in Georgia[51].

Clean energy company ***Enel*** announced its new solar panel manufacturing facility in Oklahoma under its U.S. solar panel manufacturing subsidiary 3 Sun. Enel expects to invest more than $1 billion in the new factory, and the initial production capacity will be 3 GW but may ramp up to 6 GW in later expansions.[52]

Besides tracker vendors ***NEXTracker*** and ***Array Technologies*** with their strong presence in the global PV racking market, ***Polar Racking*** will add two U.S. solar mount manufacturing facilities which will add over 1 GW of capacity from the new solar components.[53]

PV inverter manufacturer ***SolarEdge*** recently announced it will establish U.S. manufacturing capability for inverters and optimizers,[54] while Solar microinverter manufacturer Enphase Energy formed a manufacturing partnership through 3 hubs with an expected capacity of 4.8-7.2GWac of U.S. microinverters per year.[55]

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[50] Ryan Kennedy. "Canadian Solar Announces 5 GW Texas Module Factory." *Pv Magazine USA*, 15 June 2023, pv-magazine-usa.com/2023/06/15/canadian-solar-announces-5-gw-texas-module-factory/.

[51] Jaynes, Cristen Hemingway. "South Korean Company Plans to Invest $2.5 Billion in New Solar Panel Factories in Georgia." EcoWatch, 11 Jan. 2023, www.ecowatch.com/solar-manufacturing-factories-georgia-south-korea-qcells.html.

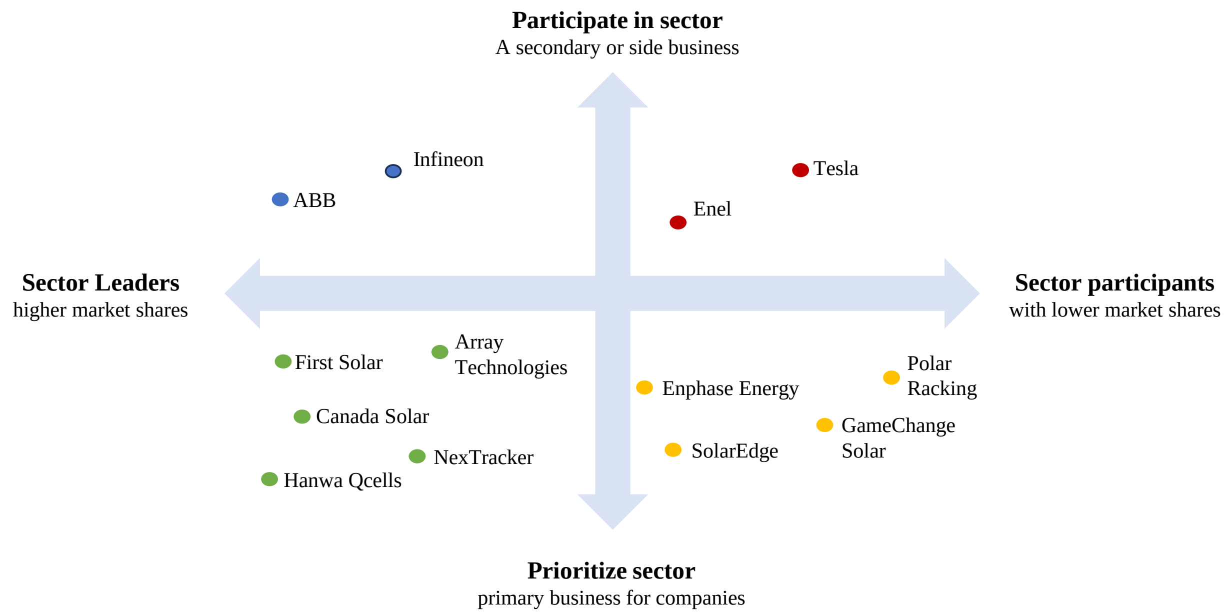
[52] Kate Magill. "Enel Chooses Oklahoma as Home of First US Solar Panel Factory." *Utility Dive*, 23 May 2023, www.utilitydive.com/news/enel-chooses-oklahoma-first-us-solar-panel-factory/.

[53] Ryan Kennedy. "Polar Racking Adds Two U.S. Solar Mount Manufacturing Facilities." *Pv Magazine USA*, 19 May 2023, https://pv-magazine-usa.com/2023/05/19/polar-racking-adds-two-u-s-solar-mount-manufacturing-facilities.

[54] Good, Allison. "Solaredge Sees US Residential Solar Recovery as New Calif. Incentives Kick In." *S&P Global Homepage*, 14 Feb. 2023, www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/solaredge-sees-us-residential-solar-recovery-as-new-calif-incentives-kick-in.

[55] Misbrener, Kelsey. "Enphase Begins US Inverter Manufacturing with Contract Partner." *Solar Power World*, 9 Aug. 2023, www.solarpowerworldonline.com/2023/07/enphase-begins-us-inverter-manufacturing-with-contract-partner/.

Figure 21. Matrix evaluation of key solar component players



Source: Columbia SIPA

2.1.4 Advanced manufacturing production for battery components

Among the numerous new and enhanced tax incentives the IRA gives to clean energy sectors, it also provides massive support for the EV and battery supply chain (lithium-ion battery) in the U.S. Less than a year after it was passed, the IRA has already spurred a wave of investment activity, especially in the U.S. downstream cell industry. It has been widely hailed as a significant shift in the dynamics of U.S. battery economics.[56]

While there has been increasing demand for EVs both domestically and internationally, the Biden Administration even before IRA set an ambitious target to make half of all new vehicles sold in 2030 zero emissions vehicles, including battery electric, plug-in hybrid electric, or fuel cell EVs.[57] Battery demand in the U.S. is expected to rise from around 36 gigawatt-hours (GWh) in 2021 to just over 800 GWh by 2032.[58] As noted already in this report, a key policy objective of the IRA is to address the low share of batteries and their component materials supplied in the U.S.

Materials used in production of battery components include the cathode (which is used to store ions when a battery is used); the electrolyte (which allows ions to move through the battery); the anode (which, during battery discharge, allows positively charged ions to flow to the cathode); and

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[56] "FACT SHEET: One Year In, President Biden's Inflation Reduction Act is Driving Historic Climate Action and Investing in America to Create Good Paying Jobs and Reduce Costs," The White House, August 16, 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/08/16/fact-sheet-one-year-in-president-bidens-inflation-reduction-act-is-driving-historic-climate-action-and-investing-in-america-to-create-good-paying-jobs-and-reduce-costs/.

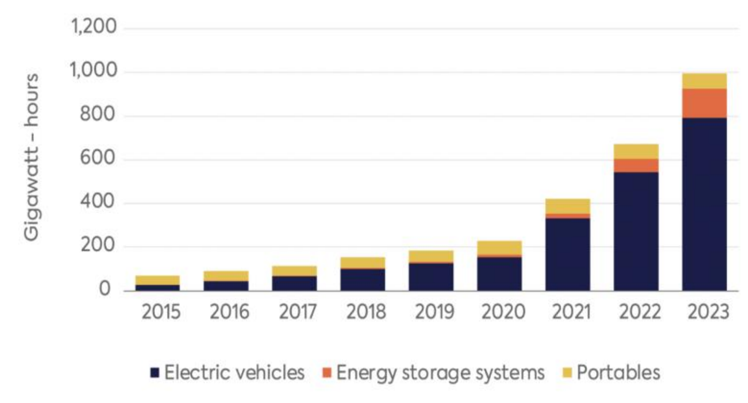
[57] Ibid

[58] "One year on, the IRA has changed the battery landscape in the US," Benchmark Source, https://source.benchmarkminerals.com/article/one-year-on-the-ira-has-changed-the-battery-landscape-in-the-us.

the separator (a barrier preventing the anode and cathode from interacting).[59] Each of these parts depends on technological advancements, engineering, and chemical reactions, all of which are ultimately dependent on the availability of vital minerals required for their manufacture.

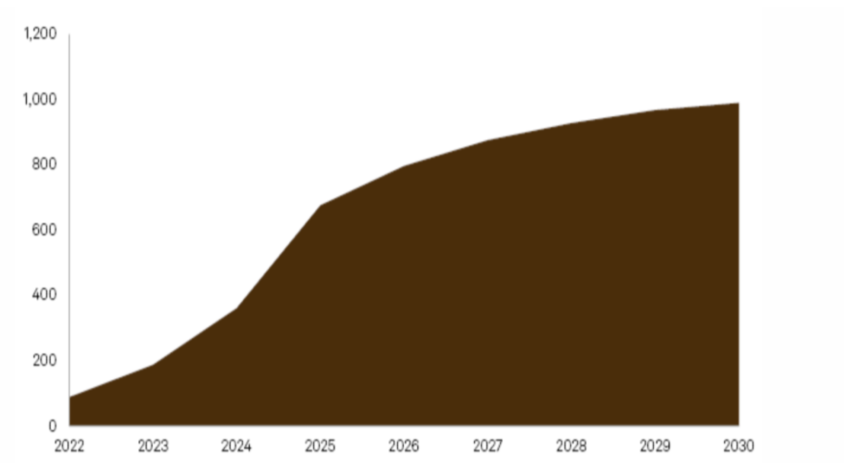
It is estimated that the U.S. alone will need 500,000 metric tons per year of unrefined lithium by 2034 just to power EVs, yet the U.S. produces just a fraction of that today. The current global production of lithium in 2020 was about 440,000 metric tons of lithium carbonate equivalent (LCE; contains about 18 percent of pure lithium), and not all of that is in pure enough form for batteries, according to Chris Doornbos, president, and CEO of E3 Metals Corp.[60]

Figure 22. Global lithium-ion battery demand by segment, 2015-2023



Source: Benchmark Mineral Intelligence

Figure 23. Planned U.S. Lithium-ion battery cell manufacturing capacity, GWh



Source: S&P Global Commodity Insights

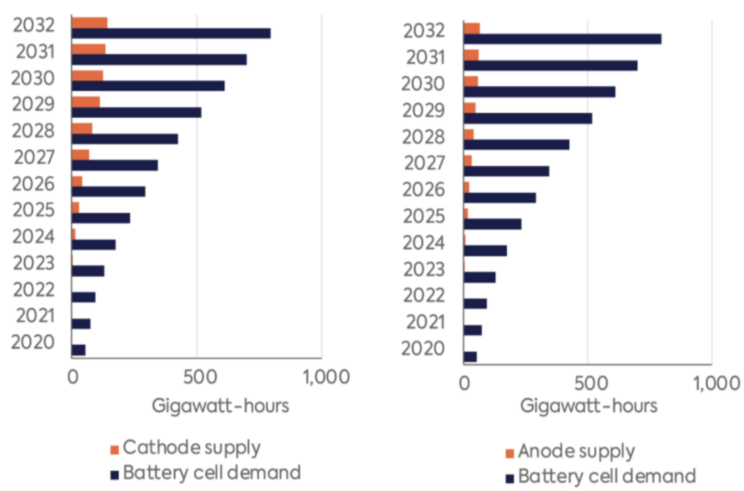
[59] "The IRA and the US Battery Supply Chain One Year On," Columbia University School of International and Public Affairs, September 2023, https://www.energypolicy.columbia.edu/publications/the-ira-and-the-us-battery-supply-chain-one-year-on/.

[60] Robert Rapier, "The US is Losing the Lithium Industry to China," Forbes, January 11, 2022, https://www.forbes.com/sites/rrapier/2022/01/11/the-us-is-losing-the-lithium-industry-to-china/?sh=33feb31416a1

While the overall cost of batteries has gone down thanks to the boom of gigafactories as well as reduction in manufacturing cost, the U.S. supply chain has a long way to go with respect to its critical mineral supply which is already tight. Presently, the two most common lithium-ion Batteries kinds are those that have lithium, iron, and phosphorus (LFP) in the cathode and those that contain nickel, manganese, and cobalt in the cathode (NMC). Cathode accounts for around 50-60 percent of battery cell costs which makes inputs like lithium of high importance. While anode materials like silicon dopants and graphite still play a crucial role in battery performance, they only account for about 10–11 percent of the total cost of the cell. Accordingly, cathode costs now determine total battery costs, which in turn determines the price of EVs.[61]

A significant impediment to regional supply security in the midstream is the cathode and anode supply/demand mismatch, which are currently estimated to be 82 percent and 92 percent, respectively (see **Figure 24**). This increases the U.S.'s exposure to Chinese imports.

Figure 24. North America cell demand vs cathode and anode supply, 2020-2032



Source: Benchmark Mineral Intelligence

Original equipment manufacturers (OEMs) have chosen the path of vertical integration in order to directly source essential minerals and reduce the risk associated with mining operations, given the sensitivity of cathode active material costs on margins. Governments have intervened at the same time to guarantee that subsidies are in place for everything from EV purchases to mining, frequently with the primary objective of bringing battery production local.

This report has already noted how a key consideration for the U.S. government addressed in the IRA is the geopolitical relevance of building a strong domestic supply chain. Senate Intelligence Committee Chair Mark Warner and Energy Committee Chair Joe Manchin cited experts saying that the U.S. is "ten to twenty years behind Asia in commercialization of battery technology," and noted that China accounts for more than 75 percent of battery cell production. Research noted in

[61] Ibid

2022 the U.S. produced less than 10 percent of lithium-ion batteries in 2022 and said demand is expected to grow over seven times by 2035.[62]

According to the 2021 BP Statistical Review, China has about eight percent of the world's lithium reserves. The U.S. has four percent. (The majority of global lithium reserves are in South America and Australia). Nevertheless, China has become the third largest lithium producer in the world, outproducing the U.S. in 2020 by more than a factor of 15 and its market share is ever increasing (by 12 percent over the last two years).[63] China also dominates the global EV battery supply chain including production of graphite - the single largest component.

2.1.4.1 Section 45X-related incentives for battery components

Under the new section 45X, three types of battery components are eligible for tax credits, electrode active materials, battery cells, and battery modules. The definitions that go along with it are narrow and don't seem to apply to supporting components by themselves. In comparison, the wind and solar categories comprise structural components that are fixed to the operative components. Therefore, Section 45X appears to be applicable only to the production of cells and modules, but not to battery cases or connecting equipment.

The incentives under the IRA for battery manufacturing are found in two categories, the supply-side push (incentives for producing batteries) and the demand-side pull (subsidies for purchasing batteries). Accordingly, battery manufacturers will be motivated to make sure their products are in compliance to receive the supply-side incentives for battery producers and that their products are also eligible for the buy-side incentives their customers would receive.

Supply Side Incentives: On the supply side, manufacturing project developers can choose between two options: (i) taking a one-time ITC (under section 48C) based on the cost of the manufacturing facility or (ii) generating continuous PTCs (under section 45X) based on their volumes of production of defined elements.

- ITC (48C): The section 48C ITC for Advanced Energy Property described already in this report could be elected to subsidize the capital cost of a new or refurbished facility for manufacturing batteries if an application to the DOE and the IRS were approved within the global maximum envelope of funding allowed under this credit ($10 billion).
- PTC (45X): This tax credit offers $10/kWh for battery modules made in the U.S. and $35/kWh for battery cells made in the U.S. It also provides for a PTC equal to 10 percent of production costs for the extraction of essential critical minerals.

Demand Side Incentives: Tax incentives for customers to purchase batteries manufactured in the U.S. occur in at least two business segments. (i) Where batteries are being purchased and deployed for energy storage, the IRA provides for a new ITC that is materially sized-up by a 10% adder if defined levels of U.S. content are present. These provisions on utility-scale battery storage deployment are analyzed more fully in Section 2.3 of this report. (ii) The EV sector is another business segment representing greater demand for batteries. Clean vehicle tax credits, known as the 30D credit and the 45W credit, encourage individual consumers and commercial fleet operators

[62] "Senators Urge US to Take Steps to Boost Battery Production Citing China," Reuters, November 6, 2023, https://www.reuters.com/technology/senators-urge-us-take-steps-boost-battery-production-citing-china-2023-11-06/
[63] Ibid

to purchase EVs. The clean vehicle credit for individual consumers is subject to local content requirements for its components and minerals, while the commercial fleet EV purchasing credit is not.

A total tax credit of $7,500 is available for purchases of full battery electric cars and plug-in hybrid EVs that meet certain local content criteria related to the origin of the critical minerals in the batteries ($3,750 credit) and the components used in the batteries (another $3,750 credit). It is possible for eligible vehicles to qualify for only one of the two credits. Purchasers can transfer the tax credit amount to retailers and receive the credit amount as a direct reduction of the cost of the vehicle.

Figure 25. IRA Section 30D criteria for compliance

IRA requirement for $7,500 clean vehicle tax credit	2024 compliance	2025 compliance
Battery component sourced from foreign entity of concern	Not compliant	Not compliant
Critical minerals sourced from foreign entity of concern	Still compliant	Not compliant
Percentage of battery components assembled in North America.	60%	60%
Percentage of critical minerals sourced from North America or a U.S. free trade partner.	50%	60%

Source: U.S. Department of Treasury, Manufacturing Dive

For the full subsidy, certain requirements need to be met, including final vehicle assembly in North America and sourcing requirements for battery components and critical minerals. Section 30D provides that the Critical Minerals Requirement (see **Table 4**) with respect to the EV's battery is satisfied if the percentage of the value of the applicable critical minerals (as defined in section 45X) contained in the battery were (i) extracted or processed in the U.S., or in any country with which the U.S. has a FTA in effect, or (ii) recycled in North America. Initially, 40 percent of these minerals must be domestically sourced, increasing yearly to 80 percent by 2027.[64] However, further challenges arise with the IRA imposing sourcing requirements for tax credits. These requirements escalate annually, presenting a significant challenge given the current dominance of non-FTA countries in critical mineral production.

Lithium is deemed the mineral most likely to meet IRA content requirements; more than 90 percent of recent U.S. lithium imports originated from FTA countries[65]. But challenges persist in the supply chains of nickel and cobalt. Nickel production is concentrated in non-FTA countries and while FTA countries produce enough refined cobalt, the U.S. currently sources 78 percent from

64 "Critical Minerals for US Climate Goals," World Resources Institute, https://www.wri.org/insights/critical-minerals-us-climate-goals

65 S&P Global Market Intelligence, "Inflation Reduction Act: Impact on North America Metals and Minerals Market," August 2023

non-FTA countries[66]. Across FTA countries, challenges such as permitting delays, litigation, environmental concerns, and opposition to mining create roadblocks.

To decouple from China and further substitute domestic production for imports, the bill also includes an exclusion criterion that battery components and critical minerals cannot come from Foreign Entities of Concern (FEOCs) including China, North Korea, Russia and Iran. Under the proposed guidance, battery cells may not be manufactured or assembled in FEOCs, and battery components must be tracked to non-covered nations.[67]

The IRA aims to reshape the U.S. battery cost curve, to lower domestic costs by $45/kWh. In principle, high-nickel U.S. batteries would post-IRA carry a cost advantage against imports of Chinese LFP cells. Importantly however, the tax credits reduce over time, from 100 percent to 75 percent in 2030, 50 percent in 2031, 25 percent in 2032, and 0 percent in 2033.[68]

Table 4. Eligible critical minerals under IRA Section 45X

Name of subsidy	Description	Critical minerals (for energy only)	Critical minerals (all)
Advanced Manufacturing Production Credit (45X)	10% production cost tax credit towards mining of critical minerals	aluminium, antimony, barite, beryllium, cerium, caesium, chromium, cobalt, dysprosium, europium, fluorspar, gadolinium, germanium, graphite, indium, lithium, manganese, neodymium, nickel, niobium, tellurium, tin, tungsten, vanadium, yttrium	Arsenic, Lanthanum, Rubidium, Titanium, Bismuth, Lutetium, Ruthenium, Ytterbium, Erbium, Magnesium, Samarium, Zinc, Gallium, Palladium, Scandium, Zirconium, Hafnium, Platinum, Tantalum, Holmium, Praseodymium, Terbium, Iridium, Rhodium, Thulium

Source: Internal Revenue Service

2.1.4.2 Recent announcements and key players for battery components

The landmark climate bill's tax credits for battery manufacturing has led to the announcement of 14 new planned battery gigafactories since July 2022.[69] According to Benchmark, the amount of U.S. gigafactory capacity that is planned out to 2030 increased from 706 GWh in July 2022—just before the IRA was signed into law—to over 1.2 terawatt-hours as of last month.

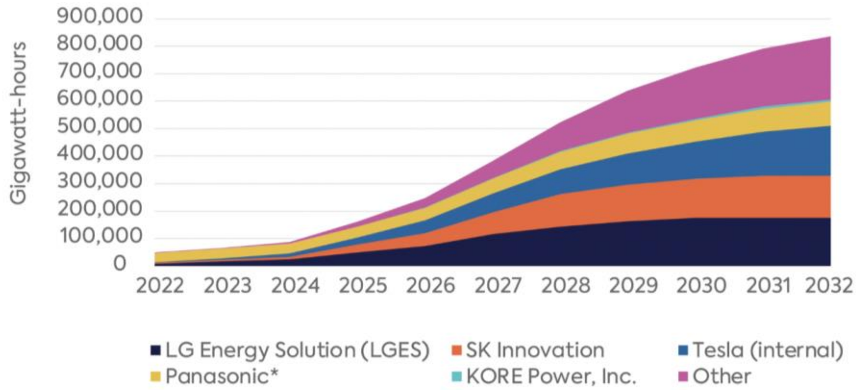
66 Ibid

67 "IRA Guidance: Foreign Entity of Concern Automakers EVs Batteries China," Manufacturing Dive. https://www.manufacturingdive.com/news/ira-guidance-foreign-entity-of-concern-automakers-evs-batteries-china/701344/

68 Ibid

69 Ibid

Figure 26. Forecasted US battery cell production by company, 2022-2032



Source:Benchmark Mineral Intelligence

With the help of South Korean joint venture partners like LGES, SKI, and Panasonic (who was also Tesla's original joint venture partner), the U.S. has so far made significant progress in the supply of cells, driven by the company's front-runner, Tesla.

In the realm of established players, ***Tesla*** stands out as a frontrunner, having established a joint venture factory in Nevada with ***Panasonic Holdings Corp***. Over the years, this facility has significantly expanded, growing from 10 GWh of cell capacity in 2017 to an impressive 37 GWh. In a major move announced in January, Tesla committed more than $3.6 billion to further expand EV and battery cell manufacturing at the Gigafactory Nevada complex, including the production of its own cells.[70]

The DOE's conditional loan of up to $9.5 billion for a joint venture between ***Ford*** and South Korean battery maker ***SK On Co. Ltd***. to build three plants in Kentucky and Tennessee to make batteries for Ford EVs is the largest battery factory deal since the IRA went into effect. Additionally, Ford has committed $3.5 billion to building a battery plant in Michigan, utilizing technology from the largest battery manufacturer in the world, Contemporary Amperex Technology Co. Ltd. in China.[71]

Another significant partnership involves ***LG*** and ***Honda Motor Co. Ltd*.**, currently working on a $3.5 billion joint venture battery plant under construction in Ohio.[72] Additionally, LG has plans to initiate the construction of a $5.5 billion lithium-ion battery hub in Queen Creek, Arizona, touted as the largest standalone battery manufacturing facility in North America.

Turning to the emerging players, ***Our Next Energy Inc. (ONE)*** is a Michigan-based battery upstart

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[70] Alan Ohnsman, "Tesla Pouring $3.6 Billion into Nevada Plant for EV Battery, Semi Production," Forbes, January 24, 2023. https://www.forbes.com/sites/alanohnsman/2023/01/24/tesla-pouring-36-billion-into-nevada-plant-for-ev-battery-semi-production/?sh=22a2674c11ef

[71] "Ford-SK Joint Venture Set to Receive $9.2 Billion US Government Loan for Battery Plants," Reuters, June 22, 2023. https://www.reuters.com/markets/asia/ford-sk-joint-venture-set-receive-92-billion-us-government-loan-battery-plants-2023-06-22/

[72] "LG Energy Solution and Honda Break Ground for New Joint Venture EV Battery Plant in Ohio," PR Newswire. https://www.prnewswire.com/news-releases/lg-energy-solution-and-honda-break-ground-for-new-joint-venture-ev-battery-plant-in-ohio-301758629.html

playing a key role in supplying energy storage systems for a substantial 420 MWh microgrid. It has raised $325.6 million from investors, including Breakthrough Energy LLC founded by Bill Gates.[73]

KORE Power Inc., based in Idaho, has secured a conditional $850 million DOE loan to support its ambitious plans for a cell and module complex in Buckeye, Arizona.[74] With financial backing from Honeywell International Inc. and Siemens AG, KORE Power broke ground on its project at the end of 2022. These new entrants are making strategic moves to establish themselves in the competitive battery market, showcasing the industry's dynamic landscape with a mix of established giants and promising newcomers.

The IRA has also led to significant investments by automakers and miners in the U.S. battery supply chain. OEMs are proactively responding to the IRA, strategically screening IRA-compliant tonnages and structuring offtakes that align with tax credit requirements. Industry giants such as Tesla, Ford, and ***General Motors (GM)*** have forged partnerships with FTA–compliant players to ensure compliance. Overall, firms have initiated new projects valued at over $400 billion, driven by incentives linked to the IRA.[75] For instance, GM's $650 million investment in Lithium Americas Corp. to develop the Thacker Pass lithium project in Nevada exemplifies this trend.[76]

Stellantis, the parent company of Chrysler and Jeep, announced a significant investment of over $100 million in ***Controlled Thermal Resources***, a California-based company.[77] This investment is part of Stellantis' strategy to secure new sources of lithium and has increased its lithium purchase agreement with Controlled Thermal to 65,000 metric tons annually for at least a decade, starting from 2027. Controlled Thermal is investing over $1 billion to extract lithium from geothermal brines beneath California's Salton Sea and plans to begin constructing a commercial lithium plant in 2024.[78] Controlled Thermal also has an agreement to supply lithium to GM, although the initial goal of starting supply by 2024 has been delayed to 2025.[79]

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[73] "IRA at 1: US Climate Law Cues $63B Spending Spree on Battery Factories," S&P Global Market Intelligence, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/ira-at-1-us-climate-law-cues-63b-spending-spree-on-battery-factories-76839524

[74] "US Set to Loan Kore Power $850 Mln for Arizona Battery Cell Plant," Reuters, June 9, 2023. https://www.reuters.com/business/energy/us-set-loan-kore-power-850-mln-arizona-battery-cell-plant-2023-06-09/

[75] Ahmed Mehdi, Tom Moerenhout, "The IRA and the US Battery Supply Chain One Year On," Center of Global Energy Policy, Columbia University School of International and Public Affairs, September 2023.

[76] Stellantis, "Stellantis Invests in CTR to Strengthen Low Emissions U.S. Lithium Production," August 17, 2023, https://www.stellantis.com/en/news/press-releases/2023/august/stellantis-invests-in-ctr-to-strengthen-low-emission-us-lithium-production.

[77] Ibid

[78] Ibid

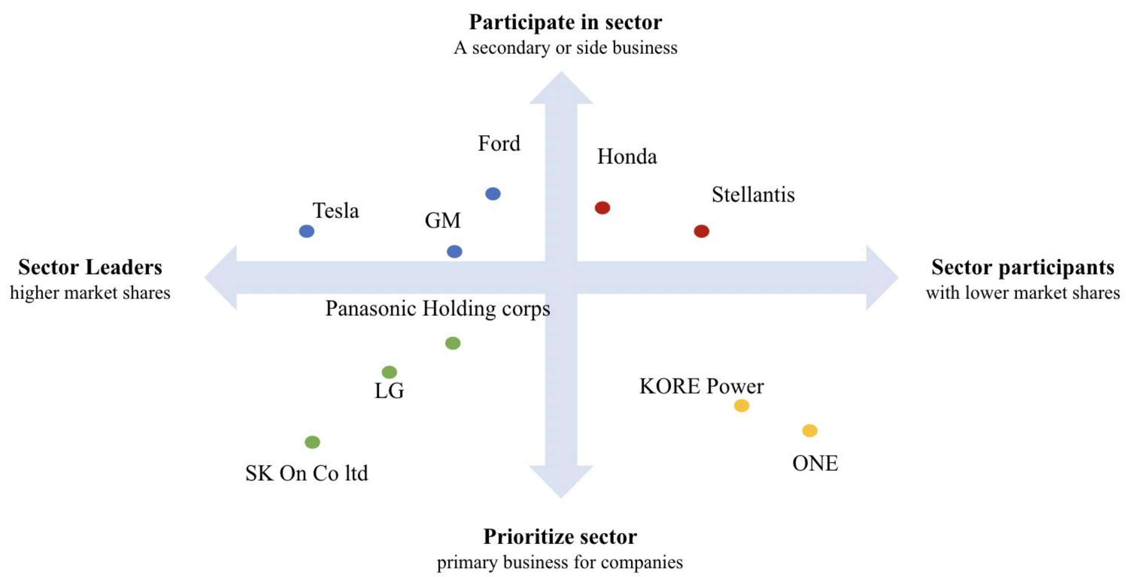
[79] Ibid

Table 5. Examples of U.S. OEM post-IRA deals to secure IRA-compliant material

OEM	Segment	Partner
Ford	Lithium	Compass
GM	Lithium	Lithium Americas
	Cobalt	Queensland Pacific Metals
	Nickel	Vale
		Queensland Pacific Metals
Tesla	Graphite	Magnis

Source: Columbia SIPA, Center on Global Energy Policy

Figure 27. Matrix evaluation of key players for battery component manufacturing



Source: Columbia SIPA

2.1.5 Mining and refining of critical minerals

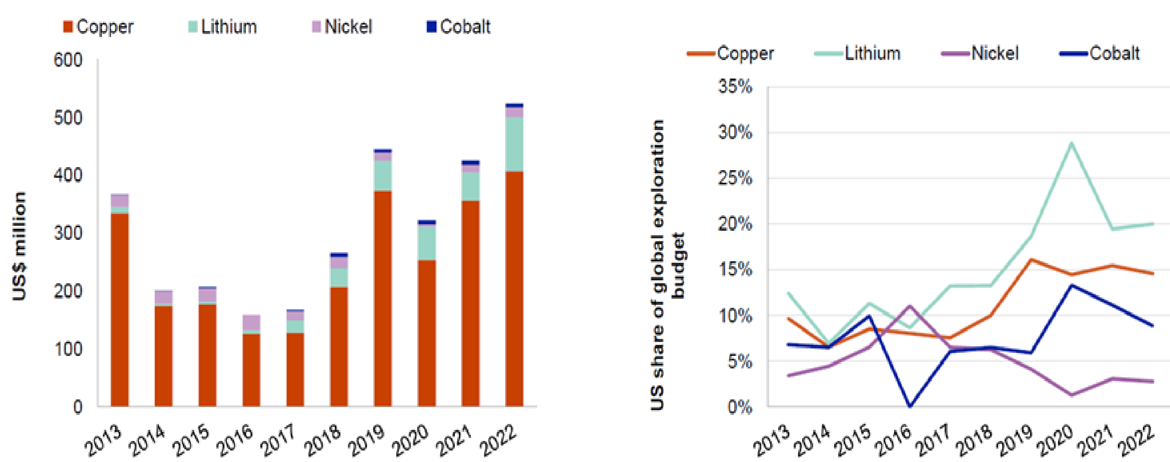
As noted already, the IRA and other Federal programs have evolved to promote U.S. production of rare elements used in producing batteries and other equipment linked to climate mitigation. The classification and definition of "critical minerals" is a key part of these measures. The Energy Act of 2020 specifies a "critical mineral" as any non-fuel mineral, element, substance, or material that (i) presents a high risk of supply chain disruption and (ii) is vital for energy technologies including production, transmission, storage, and conservation.[80] Additionally, the Secretary of the Interior, via the Director of the U.S. Geological Survey, can designate any substance as a critical mineral.

In response to these challenges, the DOE published 13 supply chain assessment reports in 2022, identifying bottlenecks in stages ranging from mining to manufacturing. These bottlenecks, intensified by the COVID-19 pandemic, arise from material and equipment shortages, workforce limitations, logistics, regulatory complexities, and market fluctuations. Overcoming these challenges necessitates a strong domestic manufacturing sector, focusing on advanced methods in extraction, substitution, recycling, and remanufacturing.

Moreover, the DOE's Critical Materials Assessment (CMA) from July 2023 emphasizes the importance of rare earth materials for magnets in EV motors and inverters, hydrogen electrolyzers as well as wind turbines for net-zero carbon emission goals but difficulties are faced due to low yield and high costs.[81] In addition, as electrode raw materials become increasingly significant in the evolving battery industry as mentioned in Section 2.1.5, expenses linked to critical minerals such as lithium, nickel and cobalt have become pivotal.[82]

Challenges remain as the permitting of mining projects in the U.S. is a complex process, entangled in federal, state, and local regulations. It involves numerous regulatory bodies, community consultations, and the management of environmental, safety, and waste concerns. Legal challenges can prolong and add costs to the process, which on average can take up to 20 years from discovery to production, with permitting alone lasting 7-10 years.[83]

Figure 28. U.S. mining exploration budgets (left) and U.S. share of global mining exploration budgets by mineral (right)



Source: S&P Global Commodity Insights

[80] U.S. Department of Energy. "What are Critical Materials and Critical Minerals?" Department of Energy, https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals.

[81] U.S. Department of Energy. Critical Materials Assessment. July 2023

[82] Ibid

[83] S&P Global, "Inflation Reduction Act: Impact on North America metals and minerals market," August 2023

Figure 29. Mines in the U.S., and U.S. reserves and resources by mineral (left) and stage (right)

Mines in the United States by mineral and stage

Status	Cobalt	Copper	Lithium	Nickel
Operating	0	25	2	1
Pre-production and feasibility	1	8	9	0
Possible	8	112	72	5

US reserves and resources by mineral and stage, thousands of metric tons

Status	Cobalt	Copper	Lithium	Nickel
Operating	0	104,956	0	73
Pre-production and feasibility	25	91,514	26,652	218
Possible	28	41,206	13,363	0

Preproduction and feasibility = preproduction, construction planned or construction stage, commissioning, feasibility complete or started
Possible = reserves development, advanced exploration, exploration, prefeasibility/scoping, late-stage, target outline

Source: S&P Global Commodity Insights

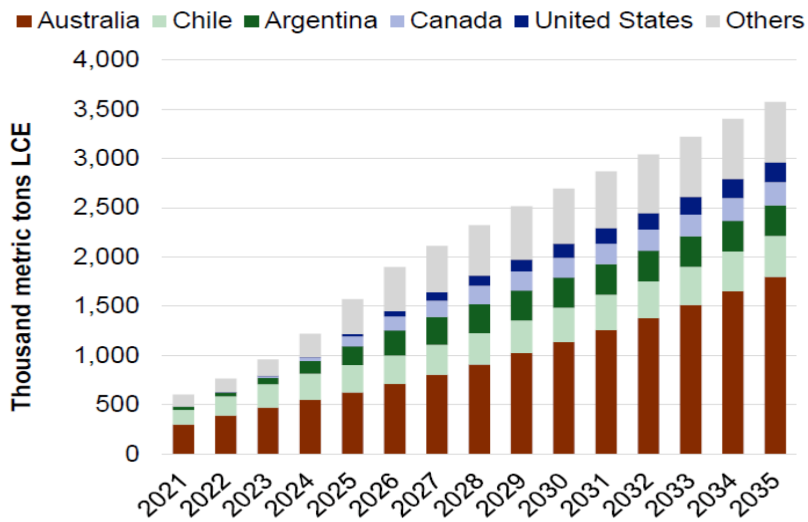
2.1.5.1 Section 45X-related incentives for mining/refining of critical minerals

In response to concerns over supply chain vulnerability and geopolitical rivalries already highlighted in Section 2.1.5 of this report above, the IRA seeks to address these challenges by providing a 10 percent production cost credit for mining or refining of critical minerals among the 45X tax credits.[84] Qualifying minerals must be domestically produced in the U.S. and developers can claim these credits without specific approval from the DOE or the IRS. These uncapped credits for critical mineral production are also not subject to the phaseout starting in 2030, unlike other eligible components.[85]

In the wake of the IRA, the U.S. is poised for substantial growth in the production of critical minerals, particularly lithium, nickel, and cobalt. The U.S. is increasing its lithium mining, and this is expected to meet the country's needs for lithium. However, current production of cobalt and the requirements for high-quality nickel make it difficult for the U.S. to meet its own needs for these minerals. Without significant changes in investment, the U.S. will likely continue to rely on imported cobalt and nickel.

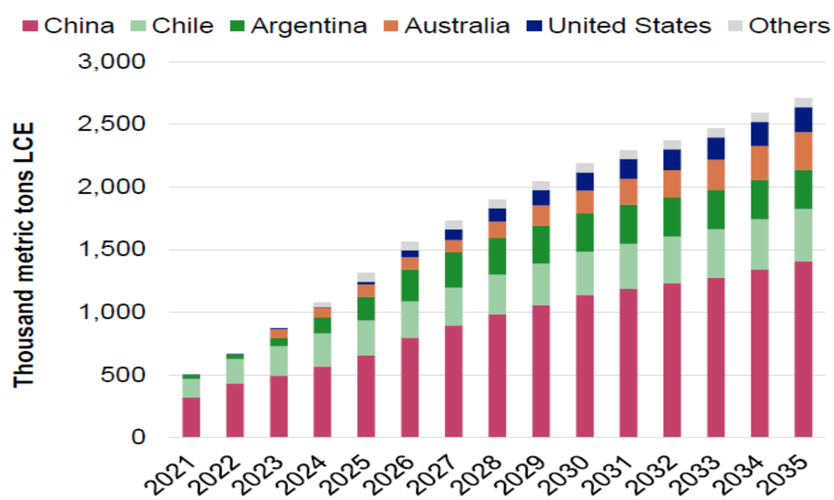
[84] H.R. 812 - 118th Congress (2023-2024): Inflation Reduction Act of 2023, H.R. 812, 118th Cong. (2023)
[85] Ibid

Figure 30. Top countries for mined lithium production, 2021 - 2035



Source: S&P Global Commodity Insights

Figure 31. Top countries for refined lithium production, 2021 - 2035



Source: S&P Global Commodity Insights

2.1.5.2 Recent announcements and key players in mining/refining critical minerals

Piedmont Lithium Inc., a U.S. lithium producer, is capitalizing on these federal investments, with plans to construct a lithium hydroxide processing plant in Tennessee.[86] This expansion is part of the company's efforts to meet the increasing demand for lithium-driven by the surge in EV production. Furthermore, Piedmont Lithium Inc. is actively working on obtaining permits and approvals for its Piedmont lithium project in North Carolina.[87] This project is expected to

[86] Ibid
[87] Ibid

commence construction in 2024, reflecting the company's commitment to expanding its lithium production capacity.

Albemarle, a U.S. specialty chemicals company, announced the location for a new lithium processing plant, which will be situated in Chester County, South Carolina. The construction of this plant is slated to start at the end of 2024, with Albemarle planning to invest a total of $1.3 billion in the project.[88] The facility is expected to initially produce about 50,000 tonnes of battery-grade lithium hydroxide per year, with plans to potentially expand this capacity to 100,000 tonnes[89]. This level of production is anticipated to support the manufacture of batteries for approximately 2.4 million EVs annually.

Lithium players, recognizing the IRA's impact, are also responding through mergers. ***Allkem Limited*** signed a definitive agreement to acquire ***Livent Corporation*** in a merger of equals transaction valued at $3.8 billion.[90] The merged entity, named ***Arcadium Lithium plc***, will have a combined value of $10.6 billion and a primary listing on the NYSE, with a foreign exempt listing on the ASX.[91] The deal, expected to close by the end of 2023. Livent has recently enlarged its lithium hydroxide processing facility in Bessemer City, North Carolina, enhancing its production capacity by 50 percent.[92] This expansion is credited to the influence of the IRA.

Exxon Mobil announced its entry into the lithium production market, aiming to start in Arkansas by 2026. The plan, known as "Project Evergreen," involves a partnership with Tetra Technologies to produce at least 10,000 metric tons of lithium annually, enough for about 100,000 EV batteries.[93] The company has also been exploring the Smackover Formation, a region rich in lithium and bromine, spanning from Florida to Texas. Apart from the partnership with Tetra, Exxon also controls over 100,000 acres in Arkansas, acquired from Galvanic Energy, and plans to start lithium production there by 2027.[94] However, Exxon and other companies face regulatory challenges in Arkansas. The state has a royalty structure for bromine but not for lithium, which could delay development.

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88 "Albemarle." Electrive, 23 Mar. 2023, https://www.electrive.com/2023/03/23/albemarle.

89 Ibid

90 "Allkem Limited (ASX:AKE) signed a definitive agreement to acquire Livent Corporation (NYSE:LTHM) in a merger of equals transaction for $3.8 billion." S&P Global, https://www.capitaliq.spglobal.com/web/client#company/keyDevelopments. Accessed November 2023.

91 Ibid

92 "Electric Vehicle Push Returns North Carolina to Its Lithium Mining Roots," The New York Times. November 30, 2023.

93 "Exxon aims to begin lithium production by 2026 in Arkansas," Reuters. https://www.reuters.com/markets/commodities/exxon-aims-begin-lithium-production. Accessed November 2023.

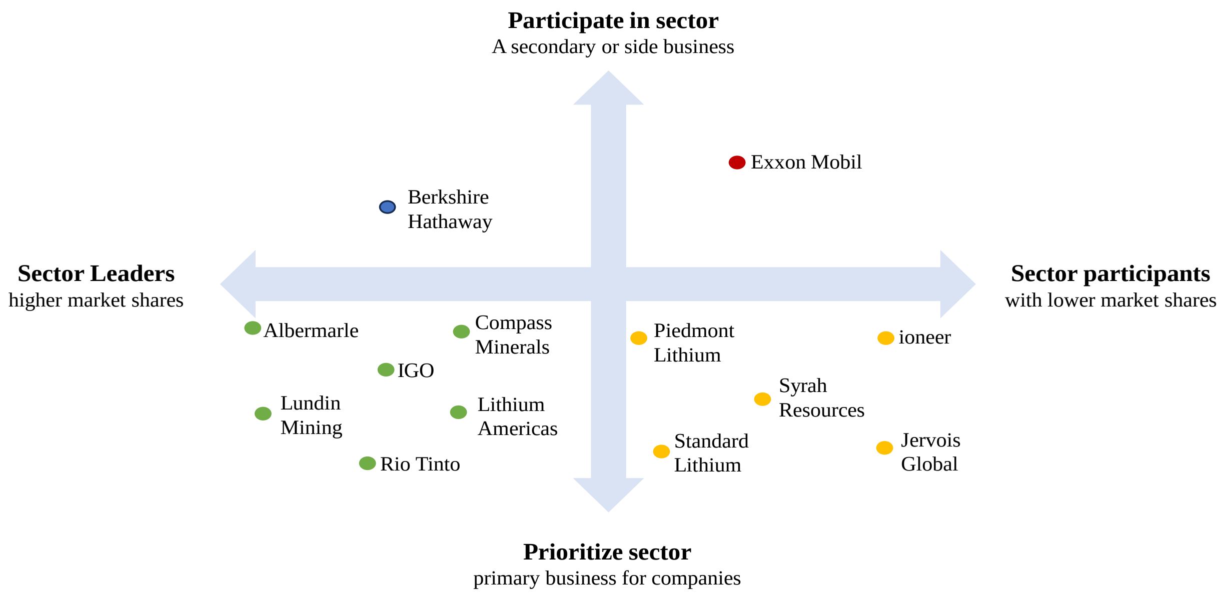
94 Ibid

Table 6. Publicly listed players in mining industry

Company	Critical Mineral	Market Capitalization (US$ billion)
Berkshire Hathaway Inc.	Lithium	788.7
Exxon Mobil Corp.	Lithium	422.8
Rio Tinto Group	Lithium	108.9
Albermarle Corp.	Lithium	13.7
Lundin Mining Corp.	Nickel	4.7
IGO Ltd.	Cobalt, Lithium, Nickel	4.2
Compass Minerals International Inc.	Lithium	0.98
Lithium Americas	Lithium	0.9
Piedmont Lithium Inc.	Lithium	0.4
Standard Lithium Ltd.	Lithium	0.4
Syrah Resources	Graphite	0.28
ioneer	Lithium	0.21
Jervois Global Ltd.	Cobalt	0.06

Source: S&P Global, data accessed November 2023

Figure 32. Matrix evaluation of key players for mining/refining of critical minerals



Source: Columbia SIPA

2.2 Clean hydrogen

2.2.1 Importance of clean hydrogen for the energy transition

Hydrogen is considered a potential solution to reduce greenhouse gas (GHG) emissions in hard-to-abate sectors due to several qualities. First, due to its high gravimetric energy intensity (120MJ/kg compared to gasoline's 44MJ/kg) hydrogen is considered an alternative fuel for mobilities requiring less heavy energy solutions, such as aviation, maritime, and heavy-duty vehicles (HDV).[95] Second, hydrogen is an energy carrier that can be stored in large quantities (GWh scale) for long periods (inter-season).[96] The need for grid and energy storage investments will increase as the share of intermittent and non-dispatchable renewable power generation increases. During periods of excess variable generation, power can be used to produce hydrogen which can be later converted back to power when there is excess electricity demand. It has been estimated that hydrogen's storage/discharge capacities could mitigate the need for additional investment of at least $21.4 trillion in the grid infrastructure required to meet the 2050 NZE goals.[97]

For some industrial sectors, hydrogen is considered one of the most viable solutions for carbon abatement. Hydrogen can replace the coking coal used in steelmaking's iron ore reduction process. Low-carbon, high-temperature heat generated by hydrogen can replace the current fossil-fuel-based heat needed for the cement and aluminum industry.[98]

The role anticipated for hydrogen in the energy transition presumes it can be produced without material GHG, resulting in "*Clean Hydrogen*." Currently, hydrogen is primarily produced in carbon-intensive processes, such as Steam Methane Reforming (SMR; 62 percent of total hydrogen production in the world) and Coal Gasification (21 percent). It is also produced as a by-product in petrochemical processes (16 percent).[99] Although less common today, producing hydrogen in less carbon-intensive methods are also possible (e.g., capturing and then sequestering carbon emitted during the hydrogen production or by electrolysis - separating water into hydrogen and oxygen by using electricity).

The DOE does not use so-called "color codes" of hydrogen and supports source-neutral pathways with regard to hydrogen production technology. However, market participants, policy makers and academia have come to refer to hydrogen by an array of following colors as shorthand for production methods[100] for communication purposes, although the exact definition may vary.

- **Gray Hydrogen**: Hydrogen produced from fossil fuel, commonly using the steam SMR method.
- **Black or Brown Hydrogen**: Hydrogen produced from the gasification of coal.
- **Blue Hydrogen**: Sourced from fossil fuels, but carbon dioxide (CO_2) emitted during the process is captured and sequestered underground.

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[95] "Hydrogen Storage." U.S. Department of Energy, www.energy.gov/eere/fuelcells/hydrogen-storage. Accessed 8 Dec. 2023.

[96] Wieliczko, Marika, and Ned Stetson. "Hydrogen technologies for energy storage: A perspective." MRS Energy & Sustainability, 9 Dec. 2020, https://www.cambridge.org/core/services/aop-cambridge-core/content/view/D308E44E8EB8BF7215ADE1621AE5DDE6/S2329222920000434a.pdf/hydrogen-technologies-for-energy-storage-a-perspective.pdf.

[97] Bloomberg New Energy Finance, 2023, The New Energy Outlook: Grids.

[98] Bloomberg New Energy Finance, 2020, Hydrogen Economy Outlook.

[99] International energy Agency. Global Hydrogen Review 2023. www.iea.org/reports/global-hydrogen-review-2023.

[100] "Hydrogen Colours Codes." H2 Bulletin, 6 Feb. 2021, www.h2bulletin.com/knowledge/hydrogen-colours-codes.

- **Green Hydrogen**: Produced through the water electrolysis process that separates water into hydrogen and oxygen by employing renewable electricity.

While the color codes for classifying types of hydrogen exist in the market, and both Blue and Green are generally considered as "clean," the IRA defines a range of carbon intensity thresholds for tax credit eligibility as *clean hydrogen*: 4kg of CO_2 equivalent emission for producing 1kg of hydrogen (4kgCO_2eq/H_2kg) and 0.45kgCO_2eq/H_2kg to become the cleanest hydrogen.[101] Clean hydrogen for the IRA incentives effectively includes, but is not limited to, Green Hydrogen and Blue Hydrogen when CCUS technology is used to reduce emissions below the thresholds. However, it's defined, clean hydrogen must overcome challenges in its value chains to become a useful solution toward Net-Zero.

From the production perspective, clean hydrogen has been too expensive and needs to be scaled up. In the case of Green Hydrogen, using renewable electricity for electrolysis is costly.[102] According to the DOE, Green Hydrogen costs around $5 in the U.S.[103] The cost of carbon capture for Blue Hydrogen did not provide offsetting financial benefits except for the Enhanced Oil Recovery (EOR) before the IRA. Indeed, 15 out of 16 Blue Hydrogen production facilities with carbon capture were dedicated to EOR[104] with only 40-60 percent carbon capture efficiency.[105]

There have been insufficient precedents to reliably calculate the costs of dedicated carbon capture in producing hydrogen. Although some process modeling studies suggest around a 50 percent increase compared to an unabated SMR process[106], for Blue Hydrogen to be considered as clean hydrogen, a significant portion of carbon emission must be captured: Currently the carbon intensity of hydrogen production from natural gas utilizing SMR is 9 kgCO_2eq/H_2kg. If upstream and midstream emissions of natural gas are added, an additional 2.4 kgCO_2eq/H_2kg can result from using median upstream and midstream emission of natural gas (15 kgCO_2eq per GJ).[107]

Even if the production costs reach $1/kg by 2030 as the DOE targets[108], the use would be limited due to price competitiveness; $1/$H_2$kg would be translated to an electricity price of $30/MWh, natural gas price of $8.8/MMBtu, and U.S. crude oil price of $50/barrel on an energy equivalent basis.

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[101] "Sec. 45V. Credit For Production Of Clean Hydrogen." Bloomberg Tax Irc, irc.bloombergtax.com/public/uscode/doc/irc/section_45v.

[102] *Using renewable energy*: There is a policy dispute among participants and observers in the Green hydrogen market concerning the use of grid-sourced power to run electrolyzers. Some advocates are urging a broad definition of Green hydrogen that would permit the use of grid sourced power so long as the volume of power consumed in running electrolyzers is matched by generation from new renewables sources feeding the grid from some other site. Advocates for this broad definition argue that requiring Green hydrogen production be powered directly from renewable sources is both costly and inefficient as the utilization rate for Green hydrogen production would be limited by the factors that limit renewable generation (e.g. wind speeds, daylight, solar intensity). Advocates for a narrow definition argue using grid power for a new demand source like Green hydrogen could result in a net increase in GHG emissions from fossil fuel generation on the grid. The DOE is weighing this issue; some guidance from the DOE and the U.S. Treasury on the eligibility for IRA tax credit in the case of Green hydrogen produced from grid sourced power is anticipated

[103] Department of Energy. Hydrogen Shot. www.energy.gov/eere/fuelcells/hydrogen-shot.

[104] "Natural Gas Explained." U.S. Energy Information Administration (EIA), www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php.

[105] Ibid, p79

[106] Ibid, p79

[107] Ibid, p87-88

[108] Department of Energy. Hydrogen Shot. www.energy.gov/eere/fuelcells/hydrogen-shot.

From the distribution perspective, more hydrogen infrastructure will be needed for clean hydrogen to serve all its hoped-for uses. Today, hydrogen pipelines in the U.S. are installed in regions with high levels of production and use, such as the Gulf Coast petrochemical complexes, but the total length is just 1600 miles.[109] For comparison, the entire length of natural gas pipelines in the U.S. is around 3 million miles.[110] However, scaling up hydrogen would require additional hydrogen pipelines as it is considered the cheapest option for hydrogen transportation up to 2000-2500km[111] (1250m-1550m), and hydrogen pipelines can replace traditional power transmission for offshore wind power projects farther than 300km (185 miles) due to its cost-efficiency. [112] Repurposing the existing LNG pipeline or blending hydrogen with natural gas could lower the investment need. However, repurposing pipelines may make them brittle, and there is no deblending technology available on a large scale yet. In addition, although porous reservoirs, salt caverns, and lined hard rock cavern storage are being considered, technology has yet to be demonstrated for the storage of pure hydrogen to be suitable over multiple cycles within a year.[113]

2.2.2 Development trend of clean hydrogen prior to IRA

Before the IRA, the hydrogen industry was limited to traditional carbon-intensive production methods, with hydrogen used primarily as the feedstock for industrial sectors. Companies developing electrolyzer technologies for clean hydrogen production existed, but utility-scale electrolyzer sales have not scaled up as the U.S. did not have an industrial policy towards clean hydrogen to help the industry (unlike the E.U.: "A hydrogen strategy for a climate-neutral Europe").[114] As a result, the total announced investment in the hydrogen sector before the IRA (May 2022) was only $29 B for the U.S., making up less than 15 percent of the global investment announcement of $240 B.[115]

2.2.3 IRA-related incentives for clean hydrogen

While the capital cost of a hydrogen production facility is among the range of investments that may be eligible for the competitively awarded the section 48C Advanced Energy Property ITC described already in this report, the key more-impactful subsidy within the IRA related to clean hydrogen is a newly introduced PTC aimed at netting-down production costs (Section 45V). [116] This clause is consistent with the previously announced hydrogen shot policy (June 2021), which targeted clean hydrogen production costs at $1/H_2kg$ within a decade.

As noted above, the carbon emission should be 4 $kgCO_2eq/H_2kg$ at the most to be eligible for the PTC, and less than 0.45 $kgCO_2eq/H_2kg$ to be eligible for maximum PTC. The tax credit is technologically neutral, or in other words, it is not limited to certain colors of hydrogen. The base credit is solely dependent on the carbon intensity, with the credit ranging from $0.12/H_2kg$ to $0.6/H_2kg$. However, if certain prevailing wage and apprenticeship requirements ("labor

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[109] International energy Agency. Global Hydrogen Review 2023. www.iea.org/reports/global-hydrogen-review-2023.

[110] "Natural Gas Explained." U.S. Energy Information Administration (EIA), www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php.

[111] International energy Agency. Global Hydrogen Review 2023. www.iea.org/reports/global-hydrogen-review-2023.

[112] (Ibid, pp115-116)

[113] (Ibid, p111)

[114] European Commission. Communique on A Hydrogen Strategy for a Climate-Neutral Europe, 8 July 2020. eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2020:301:FIN.

[115] Hydrogen Council, Mckinsey&Company, 2023, Hydrogen Insight 2023, hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf.

[116] "Sec. 45V. Credit For Production Of Clean Hydrogen." Bloomberg Tax Irc,

standards") are satisfied, the credit is increased depending on the carbon intensity[117], as shown in **Table 7**. It is also important to note that the PTC for clean hydrogen production with electrolyzers can be stacked with the clean energy ITC/PTC (45Y) for using renewable electricity but the PTC for clean hydrogen production involving carbon capture cannot be stacked with the 45Q PTC for carbon capture.[118]

Table 7. Carbon emission threshold and corresponding hydrogen PTC

Threshold (CO_2eq kg/H_2)	<0.45	<1.5	<2.5	<4.0
Credit (H_2-kg)	$3.00	$1.00	$0.75	$0.60

Source: Bloomberg Tax

Hydrogen should be produced after 2022 from projects that began construction before Jan. 1st, 2033, to receive PTC. The carbon intensity is measured by the GREET model developed by Argonne National Laboratory. This model measures carbon emission until hydrogen enters the distribution network (Well-to-Gate). However, there are still uncertainties regarding the measurement criteria of emissions[119], including, but not limited to (i) which specific steps and emissions should be included within the well-to-gate system boundary); (ii) how should lifecycle GHG emissions be allocated to co-products from the clean hydrogen production process; and (iii) what granularity of time matching (Annual vs Hourly) of energy inputs used in the qualified clean hydrogen production process should be required?

2.2.4 Recent announcements and key players for clean hydrogen

The passage of the IRA is accelerating investments in North America. According to McKinsey & Company and the Hydrogen Council, a global CEO-led initiative for hydrogen in the energy transition, announced hydrogen projects in North America (the U.S. and Canada combined) through 2030 increased from $29 billion in May 2022 to $46 billion in January 2023.[120] More than three-quarters of investments were focused on clean hydrogen supply, followed by end use (about 15 percent) and infrastructure (about 5 percent).[121] This trend reflects the IRA's concentrated support for clean hydrogen production with the PTC. The announced projects would be able to produce 9.3Mt/year, a significant rise of 3.8Mt/year from May 2022.[122] Among them, Green Hydrogen capacity has grown by 2.5 times, though more than 70 percent of the announced capacity is still for clean hydrogen that is not Green. The capacity and weight of Green Hydrogen are much less than that of Europe, where the announced Green Hydrogen capacity is 8.7Mt/year, accounting for 35 percent of clean hydrogen production facilities announcements).[123] Such a trend is not

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[117] "The Inflation Reduction Act: The Incentives Are in the Details for Hydrogen Producers." JD Supra, 21 Dec. 2022, www.jdsupra.com/legalnews/the-inflation-reduction-act-the-5669812.

[118] "Financial Incentives for Hydrogen and Fuel Cell Projects." Department of Energy, www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects.

[119] Internal Revenue Service. Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production, 5 Oct. 2023. www.irs.gov/pub/irs-drop/n-22-58.pdf.

[120] Hydrogen Council, Mckinsey&Company, 2023, Hydrogen Insight 2023, hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf.

[121] Ibid, p20

[122] Ibid, p21

[123] Ibid, p21

unusual, considering that the IRA's PTC is technology-neutral and Blue Hydrogen production facilities can be deployed faster by retrofitting current SMR facilities.

Without the nationwide carbon market in the U.S. (although some states, including California and 11 northeast states, have implemented certain kinds of monetary burdens such as a cap-and-trade system[124]), there are limited incentives for the taxpayers to utilize clean hydrogen. Thus, the primary beneficiaries of the IRA in the hydrogen sector would be clean hydrogen producers and clean hydrogen production parts and equipment providers, where PTC will give a considerable boost. Some argue that the PTC could reach up to $100 billion depending on how the guidance concerning the implementation is set.[125] However, the effect on the end-use solution is still questionable due to the high price compared to other solutions, as noted in section b. "Importance for energy transition". Indeed, while the "U.S. National Clean Hydrogen Strategy and Roadmap" (June 2023) targets deploying GW-scale electrolyzers and developing domestic supply chains by 2029, it only targets demonstration of advanced and efficient infrastructure components in terms of delivery and storage infrastructure.[126] In addition, the federal government envisions the first application adoption phase will be jumpstarted by existing markets that have few alternatives to clean hydrogen for decarbonization, including existing refining and ammonia production plants.[127] However, apart from lower carbon emissions, replacing conventional Gray or Black Hydrogen with clean hydrogen will not bring additional financial benefits to the end users. It also expects forklifts & other material handling equipment and long-haul HDVs will be among the first to be included in the application adoption.

Many oil and gas companies such as ***ExxonMobil***[128], ***Chevron***[129], and ***Shell***[130] have shown interest in Blue Hydrogen as they can utilize their depleted oil and gas wells for carbon storage. However, since the current ambitions for Blue Hydrogen are incomparably minimal to the companies' size, they will not be included in the analysis.

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124 "U.S. State Carbon Pricing Policies." Center for Climate and Energy Solutions, www.c2es.org/document/us-state-carbon-pricing-policies/.

125 Clean Air Task Force, et. al. "RE: Implementation of the IRA 45V Clean Hydrogen Tax Credits as It Relates to Guidelines for Emissions Accounting of Grid-Connected Electrolyzers ." Received by The Honorable Lily L. Batchelder, Assistant Secretary for Tax Policy, Department of the Treasury; The Honorable Jennifer Granholm Secretary U.S. Department of Energy; et. al , 23 Feb. 2023, cdn.catf.us/wp-content/uploads/2023/02/23171218/joint-letter-45v-implementation.pdf.

126 Department of Energy. U.S. National Clean Hydrogen Strategy and Roadmap, www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?Status=Master.

127 Ibid, p73

128 "Exxon Mobil Sets Large-Scale Hydrogen Plant Start-up for 2027." Reuters, 30 Jan. 2023, www.reuters.com/business/energy/exxon-mobil-sets-large-scale-hydrogen-plant-start-up-2027-2023-01-30/.

129 "Air Liquide, Chevron, Lyondellbasell, and Uniper to Pursue Lower Carbon Hydrogen and Ammonia Project along the U.S. Gulf Coast." Chevron, 19 Oct. 2022, www.chevron.com/newsroom/2022/q4/air-liquide-chevron-lyondellbasell-and-uniper-to-pursue-lower-carbon-hydrogen-and-ammonia-project.

130 "Shell Will Spend up to $1bn Annually on Hydrogen and CCS in 2024 and 2025." Hydrogen Insight, 15 June 2023, www.hydrogeninsight.com/production/shell-will-spend-up-to-1bn-annually-on-hydrogen-and-ccs-in-2024-and-2025/2-1-1467919.

Plug Power is the world's largest producer of electrolyzers, which is critical for producing Green Hydrogen, and has a yearly production capacity of 3GW.[131] Plug Power makes proton-exchange membrane (PEM) electrolyzers, which are flexible, smaller, and have a longer life span but have a higher cost than alkaline-based competitors.[132] As fuel cell technology roughly requires the reverse reaction of what happens within the electrolyzer, Plug Power also provides fuel cells for mobility solutions such as forklift which is considered to be one of the first end-use solutions of clean hydrogen. PlugPower announced that it agreed to provide 10,950 tons of Green Hydrogen yearly starting in 2025 for hydrogen fuel cell-powered forklifts. (Aug. 2022) Its Chief Strategic Officer explained to the Economist that the IRA has had a transformational impact on the prospect of clean hydrogen.[133] In addition, they are likely to be the provider of electrolyzer solutions in some of the Regional Clean Hydrogen Hub, as Plug Power is a corporate sponsor of 5 of 7 potential candidates for U.S. regional clean hydrogen hub. However, their market cap had been shrinking significantly over the year due to the high-interest environments and supply chain challenges.[134]

Bloom Energy is another large producer of electrolyzers, claiming 2GW[135] of annual capacity, although their solid-oxide electrolyzer technology is not of mainstream types. Bloom Energy claims it has installed the world's largest solid-oxide electrolyzer (SOE) at a NASA research facility in California, producing 20-25 percent more hydrogen per MW than any commercially demonstrated PEM equivalent.[136] However, their sales are still mainly focused on natural-gas-based stationary fuel cells for commercial and utility power generation. In addition, there has yet to be a recent announcement regarding their Green Hydrogen production solutions sales.

Cummins is another large publicly listed U.S. producer of fuel cells and electrolyzers with 1.6 GW[137] of annual capacity, sold under *Accelera* brand name. Cummins acquired majority share of Hydrogenics, which was a leading electrolyzer and fuel cell producer in 2019 with Air Liquide, and recently bought out the share of Air Liquide to make Hydrogenics wholly owned subsidiary in 2023.[138] Due to its close relation to Air Liquide, it is expected that Cummins will remain as

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[131] "Chinese Companies Take Top Three Slots in BNEF's List of World's 20 Largest Hydrogen Electrolyser Makers." Hydrogen Insight, 17 Nov. 2022, www.hydrogeninsight.com/electrolysers/chinese-companies-take-top-three-slots-in-bnefs-list-of-worlds-20-largest-hydrogen-electrolyser-makers/2-1-1355610.

[132] "Green Hydrogen | Which Type of Electrolyser Should You Use? Alkaline, PEM, Solid Oxide or the Latest Tech?" Hydrogen Insight, www.hydrogeninsight.com/electrolysers/green-hydrogen-which-type-of-electrolyser-should-you-use-alkaline-pem-solid-oxide-or-the-latest-tech-/2-1-1480577.

[133] "America's Chance to Become a Clean-Energy Superpower." The Economist, 5 Apr. 2023, www.economist.com/united-states/2023/04/05/americas-chance-to-become-a-clean-energy-superpower.

[134] "Plug Power's Stock Plunges 25% as Company Sees 'unprecedented Supply Challenges." Market Watch, 9 Nov. 2023, www.marketwatch.com/story/plug-powers-stock-plunges-12-as-company-sees-unprecedented-supply-challenges-fc581a18.

[135] "Bloom Energy Demonstrates Hydrogen Production with the World's Most Efficient Electrolyzer and Largest Solid Oxide System." Bloom Energy, 3 May 2023, newsroom.bloomenergy.com/news/bloom-energy-demonstrates-hydrogen-production-with-the-worlds-largest-and-most-efficient-solid-oxide-electrolyze.

[136] Ibid

[137] "New Global Leader | Bloom Energy Increases Annual Hydrogen Electrolyser Production to 2GW." Hydrogen Insights, www.hydrogeninsight.com/electrolysers/new-global-leader-bloom-energy-increases-annual-hydrogen-electrolyser-production-to-2gw/2-1-1345629.

[138] 27. "Cummins Takes 100% Ownership of Hydrogen Electrolyser Subsidiary Hydrogenics after Buying Air Liquide's 19% Stake." Hydrogen Insight, 3 July 2023, www.hydrogeninsight.com/electrolysers/cummins-takes-100-ownership-of-hydrogen-electrolyser-subsidiary-hydrogenics-after-buying-air-liquides-19-stake/2-1-1479173.

important supplier of Air Liquide,[139] which is boasts heavy presence in Regional Clean Hydrogen Hubs. Cummins had recently marked the start operations for electrolyzer production in the U.S. in May 2023. It also shared that since the passing of the U.S. Bipartisan Infrastructure Law and the IRA, the business has received committed orders for nearly 300 MW of electrolyzer projects in North America, which will produce approximately 150 tons of hydrogen per day.[140]

Linde is a major supplier of industrial gases, including hydrogen. With their expertise in industrial gases, they possess a strong distribution infrastructure worldwide. Linde announced in February this year that they will invest $1.8 billion to supply Blue Hydrogen as a feedstock to OCI's new ammonia plant from 2025 in Texas. It subsequently announced that ExxonMobil would store the CO_2 captured from the operation. The company's CEO, Sanjiv Lamba, cited the "support from the U.S. Inflation Reduction Act" as a reason why "the company is well positioned to secure many more clean energy projects."[141]

Air Product is another industrial gas company based in the U.S. Joining with power utility conglomerate AES Corp to build a $4 billion Green Hydrogen production (200t/day) plant including 1.4GW of wind and solar in Texas. (Dec. 2022) It also announced its $4.5 billion investment plan to build the world's largest Blue Hydrogen facility in Louisiana, which is targeted for 2026. The company's CEO cited the IRA's tax incentive on Green Hydrogen as "a significant positive event" as they "moved forward with detailed planning to execute this project."[142]

Air Liquide is a French industrial gas company seen as a beneficiary of the energy transition, supported by both the IRA and E.U.'s net zero emission goals.[143] In addition, as Air Liquid is a partner for 6 of 7 potential candidates for U.S. regional clean hydrogen hub projects, their clean hydrogen production and distribution solutions will get an extra boost from the Bipartisan Infrastructure Bill in addition to the IRA's PTC.

While the Blue Hydrogen business would currently have relatively minimal impact on the values of gas and oil companies, Blue Hydrogen solutions-providers stand to benefit materially from PTCs within the IRA. ***Technip Energies***, a French Engineering and technology company that provides solutions for energy industries, could benefit from the growth of Blue Hydrogen. As Technip Energies has a long history of delivering hydrogen plant solutions to various partners around the world,[144] it will benefit from new SMR plants where carbon emissions will be captured to produce Blue Hydrogen. Moreover, in addition to having a close relationship with Shell for

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[139] Ibid

[140] "Accelera Marks Start of Operations for Electrolyzer Production in Fridley, Minnesota." Businesswire, 19 May 2023, www.businesswire.com/news/home/20230519005317/en.

[141] "Linde to Invest $1.8 Billion to Supply Clean Hydrogen to OCI's World-Scale Blue Ammonia Project in the U.S. Gulf Coast." Linde, 6 Feb. 2023, www.linde.com/news-media/press-releases/2023/linde-to-invest-1-8-billion-to-supply-clean-hydrogen-to-oci-s-world-scale-blue-ammonia-project-in-the-u-s-gulf-coast.

[142] "Air Products To Go Ahead With $7 Billion Hydrogen Project In Louisiana With Carbon Capture Included." Carbon Herald, 16 Nov. 2023, carbonherald.com/air-products-to-go-ahead-with-7-billion-hydrogen-project-in-louisiana-with-carbon-capture-included.

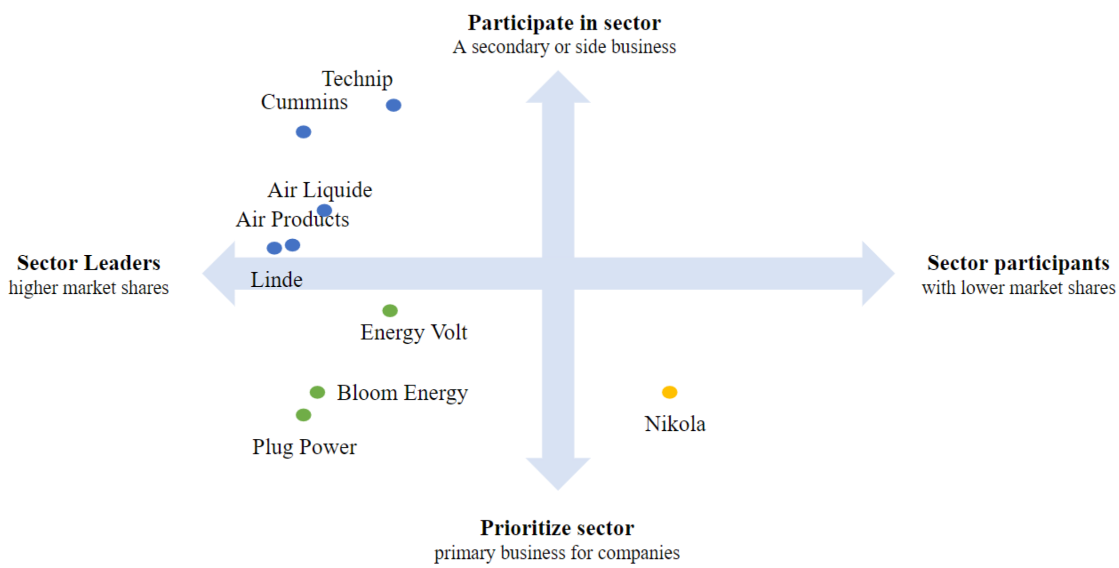
[143] "Air Liquide Bets on US Energy Transition as Investments Hit Record 4 Bln Euros." Reuters, 25 Oct. 2023, www.reuters.com/business/energy/industrial-gases-firm-air-liquide-q3-revenue-drops-energy-prices-ease-2023-10-25/.

[144] Hydrogen, Technip Energies, 2022, www.ten.com/sites/energies/files/2022-05/Brochure_Hydrogen_WEB.pdf.

carbon capture,[145] in January 2023, it has recently received a front-end engineering and design (FEED) award for Blue Hydrogen plant by ExxonMobil in Houston, which will eventually produce more than 0.8 million tons of Blue Hydrogen per year (1 billion cubic feet per day).[146] Such announcements demonstrate Technip Energies potential as Blue Hydrogen solutions provider.

Nikola, a battery electric and fuel cell electric truck manufacturer could benefit from lower costs of clean hydrogen as the price of clean hydrogen drops, as *U.S. National Clean Hydrogen Strategy and Roadmap* expects HDV will be among the first to replace current solutions with the total costs to the end-user being below $5/$H_2$ kg. Despite previous fraud scandals involving the company founder and financial struggles, it has started commercial launch of hydrogen fuel cell electric trucks in September 2023 in Arizona.[147] The company also claims it has secured 277 orders, with orders outpacing current manufacturing capacity.[148]

Figure 33. Matrix evaluation of key players for clean hydrogen production



Source: Columbia SIPA

[145] "Shell Catalysts & Technologies and Technip Energies Strengthen Strategic Alliance on CANSOLV* Technology to Address Growing CCS Demand." 17 Oct. 2022, www.shell.com/business-customers/catalysts-technologies/resources-library/shell-catalysts-technologies-and-technip-energies-strengthen-strategic-alliance-on-cansolv-technology-to-address-growing-ccs-demand.html.

[146] "ExxonMobil Advances Major Low-Carbon Hydrogen Hub At Baytown." Forbes, 30 Jan. 2023, www.forbes.com/sites/davidblackmon/2023/01/30/exxonmobil-advances-major-low-carbon-hydrogen-hub-at-baytown/?sh=7de35451762f.

[147] Nikola Celebrates the Commercial Launch of Hydrogen Fuel Cell Electric Truck in Coolidge, Arizona, Nikola, 28 Sept. 2023, nikolamotor.com/press_releases/nikola-celebrates-the-commercial-launch-of-hydrogen-fuel-cell-electric-truck-in-coolidge-arizona/.

[148] "Nikola Receives More Orders for Fuel-Cell Truck, Posts Wider Loss." Reuters, Thomson Reuters, 2 Nov. 2023, www.reuters.com/business/autos-transportation/electric-truck-maker-nikola-reports-wider-loss-third-quarter-2023-11-02/.

2.3 Utility-Scale Battery Energy Storage Solutions

2.3.1 Importance of BESS for the energy transition

One of the key challenges of transitioning to a low-carbon energy system is the intermittency of renewables which, unlike fossil-fueled generation, cannot be dispatched on demand. To address this issue, BESS can play the following key roles:

Balancing Supply and Demand: BESS plays a crucial role in managing the balance between electricity supply and demand, especially in the context of a power grid experiencing a growing presence of variable renewable energy (VRE) sources such as wind and solar. These sources are dependent on daily and seasonal fluctuations, as well as weather variations.

Enabling Renewable Energy Integration: BESS stands out as a facilitator for enhancing power system flexibility and promoting the integration of high levels of renewable energy.[149] BESS enables the optimization of renewable resources on a scale necessary for decarbonizing the power grid by storing excess energy during periods of high VRE generation or low demand.

Supporting Grid Stability: BESS contribute to enhancing the stability of the electrical grid by offering essential services such as frequency response, reserve capacity, and black-start capability. These capabilities improve grid efficiency, allowing for a more reliable operation. BESS can optimize grid stability and on-demand energy availability.[150] Additionally, BESS can also be sited in load centers to allow grid operators to avoid costly transmission upgrades.

Battery storage can also reduce the need for costly transmission and distribution upgrades and enable greater integration of distributed energy resources.[151]

2.3.2 Development trend of BESS prior to IRA

In 2021, BESS capacity in the US witnessed exponential growth, more than tripling from 1,438 MW in 2020 to 4,631 MW. This surge coincided with the expansion of storage use cases, resulting in the addition of 3,508 MWh of new storage systems, an increase from 1,464 MWh recorded in 2020.[152] Furthermore, the emergence of solid-state batteries, known for their energy density and safety compared to lithium-ion batteries[153], could expedite the progress of BESS technologies.

While high investment costs have historically posed a challenge to widespread BESS deployment, there has been a decline in the cost of BESS systems in the past. Between 2015 and 2018, the average energy capacity cost of BESS in the U.S. plummeted by over half, decreasing from $2,152

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[149] "Energy Storage." IEA, www.iea.org/energy-system/electricity/grid-scale-storage.

[150] "Utility-Scale Energy Storage: Technologies and Challenges for an Evolving Grid | U.S. GAO." www.gao.gov, 30 Mar. 2023, www.gao.gov/products/gao-23-105583.

[151] "Enabling Renewable Energy with Battery Energy Storage Systems | McKinsey." www.mckinsey.com, 2 Aug. 2023, www.mckinsey.com/industries/automotive-and-assembly/our-insights/enabling-renewable-energy-with-battery-energy-storage-systems.

[152] "Electricity Monthly Update - U.S. Energy Information Administration (EIA)." www.eia.gov, www.eia.gov/electricity/monthly/update/.

[153] Chen, Yong, et al. "Recent Progress in All-Solid-State Lithium Batteries: The Emerging Strategies for Advanced Electrolytes and Their Interfaces." Energy Storage Materials, vol. 31, no. 31, 1 Oct. 2020, pp. 401–433, https://doi.org/10.1016/j.ensm.2020.05.019.

per kilowatt-hour (kWh) to $625 per kWh[154]. However, recent global events have recently driven up the costs.[155] The dollar-per-kilowatt ($/kW) cost of storage has risen from $1,580 in the first quarter of 2021 to $1,993 in 2022. This increase is also attributed to challenges within the supply chain for battery components. The price hikes have caused delays and cancellations in the production and delivery of BESS. As a notable example, over 1.1 GW of utility-scale storage capacity, initially slated for deployment in Q2 2022, were delayed or cancelled.[156]

The DOE's Energy Storage Grand Challenge (ESGC) has set a goal of achieving a levelized cost of storage for long-duration stationary applications at $0.05/kWh by 2030, representing a 90 percent reduction from the 2020 baseline costs[157]. Meeting this cost target would enhance the commercial viability of storage across diverse applications. Meanwhile, technological advancements, particularly in lithium-ion batteries renowned for their high energy density and extended cycle life, have played a pivotal role in shaping the landscape of new BESS in the U.S.

The cost and performance of BESS will continue to improve over time, as evidenced by data from the NREL Annual Technology Baseline (ATB). The ATB provides cost projections for utility-scale lithium-ion battery systems across various durations (2–10 hours) and scenarios (Market and policies, R&D, and Constant Technology Improvement)[158]. The ATB illustrates a 28 percent decrease in installed capital costs for utility-scale battery systems from 2019 to 2023, with an expected additional 47 percent reduction by 2030 under the R&D scenario. Additionally, fixed operation and maintenance costs for these systems have decreased by 18 percent from 2019 to 2023, and a further 25 percent reduction is projected by 2030 under the R&D scenario.

2.3.3 IRA-related incentives for BESS deployment

In section 2.1.3 above, the supply-side tax credits available under the IRA to encourage the manufacturing of lithium-ion batteries in the U.S. were outlined along with the buy-side tax credits supporting the purchase of EVs, adhering to IRA-defined content rules. Expanding on the IRA's influence, the buy-side provisions for the end-users in BESS are also poised to incentivize the deployment of such projects.

Before the IRA, an ITC could only be claimed for deploying BESS projects if the batteries were co-located with a new solar generation facility supplying a minimum of 80 percent of the power charged into that facility.[159] This was a material limitation, especially as the best sites for BESS are usually located in the brownfield sites of fossil-fueled power plants, equipped with transmission infrastructure and situated in proximity to major power loads.

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154 "Utility-Scale Battery Storage Costs Decreased Nearly 70% between 2015 and 2018 - Today in Energy - U.S. Energy Information Administration (EIA)." www.eia.gov , 23 Oct. 2020, www.eia.gov/todayinenergy/detail.php?id=45596.

155 "The Rise of Energy Storage." Www.morganlewis.com, 8 Mar. 2023, www.morganlewis.com/pubs/2023/03/the-rise-of-energy-storage#:~:text=For%20energy%20storage%2C%20the%20IRA.

156 Feldman, David, et al. Fall 2022 Solar Industry Update. 2022.

157 "Energy Storage Grand Challenge Roadmap." Energy.gov, 21 Dec. 2020, www.energy.gov/energy-storage-grand-challenge/articles/energy-storage-grand-challenge-roadmap.

158 "Annual Technology Baseline (ATB) from the National Renewable Energy Laboratory (NREL)." Nrel.gov, 2018, atb.nrel.gov/.

159 "Treasury and IRS Publish Long-Awaited Guidance on Renewable Energy Investment Tax Credit." Www.morganlewis.com, 28 Nov. 2023, www.morganlewis.com/pubs/2023/11/treasury-and-irs-publish-long-awaited-guidance-on-renewable-energy-investment-tax-credit.

Under the IRA, a new ITC was introduced through Section 48(a)(3)(A)(ix) specifically for standalone BESS projects, requiring a minimum capacity of 5 kWh.[160] These projects are eligible for either a base rate of 6 percent or a bonus rate of 30 percent, contingent on factors such as project size, and meeting prevailing wage and apprenticeship requirements. As with other buy-side incentives under the IRA, the ITC for BESS can be increased by a 10 percent adder to 40 percent if the specified domestic content requirements are met. The IRA also delinked the ITC for BESS from a specific generation source, recognizing the increasing demand for entire grids to be supported by BESS. Furthermore, the IRA established another technology-neutral ITC under Section 48E for BESS projects that commence construction after December 31, 2024, extending its applicability at least until 2033.

The newly introduced standalone tax credit for battery storage simplifies processes and broadens financing options, thereby enhancing the overall economic feasibility of storage installations. Additionally, the extension and expansion of tax credits for the variable generation of wind and solar will increase the need for power storage to stimulate the development of BESS projects in the U.S.

2.3.4 Recent announcements and key players for BESS

There have been notable announcements on BESS projects. These developments signal a shift in the energy landscape as stakeholders and industry players are responding to the IRA incentives. This section aims to explore the latest announcements and major players in BESS.[161]

NextEra Energy Resources, a leading developer/operator of wind and solar generation, is also the leader in operating battery storage capacity in the U.S., boasting 2.814 GW. The company added 980 MW in Q3 2023, solidifying its top status. ***Vistra Energy,*** a major Texas-based independent power producer with both renewable and gas-fired capacity, retains its second place standing with 1.023 GWs of storage capacity, despite not introducing new facilities during the same period. Private equity-backed players occupy the next three rankings: ***Axium Infrastructure*** holds the third position with 733 MW; ***Terra-Gen Power*** secures the fourth spot with 680 MW, having added nearly 19 MW in a California facility in Q3 2023; ***LS Power Development Affiliates*** occupies the fifth position with 615 MW.

The recent project announcements also reflect the landscape of energy storage initiatives across the U.S. In Q3 2023 alone, NextEra Energy Resources announced the 325 MW Desert Peak Energy Storage project and the 132 MW North Central Valley Energy Storage project in California. Additionally, ***Plus Power*** announced the 300.6 MW Rodeo Ranch Energy Storage project and ***Spearmint Renewable Development*** Company's 150 MW Crane 2 BESS, both projects are located in Texas.

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160 "Definition of Energy Property and Rules Applicable to the Energy Credit." Unblock.federalregister.gov, 22 Nov. 2023, www.federalregister.gov/documents/2023/11/22/2023-25539/definition-of-energy-property-and-rules-applicable-to-the-energy-credit.

161 Micek, Kassia, and Justine Coyne. "US BATTERY STORAGE: Capacity Surpasses 14.6 GW in Q3, 3.5 GW Planned in Q4." Www.spglobal.com, 14 Nov. 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/111423-us-battery-storage-capacity-surpasses-146-gw-in-q3-35-gw-planned-in-q4.

These developments underscore the momentum in expanding battery storage capacity and below is a summary of some of the major players that are involved in battery storage or utility-scale battery storage.[162]

Leaders in Utility-Scale BESS

NextEra Energy is a leading electric power company in North America, engaging in the generation, transmission, distribution, and sale of electricity to both retail and wholesale customers. NextEra Energy is actively involved in the development, construction, and operation of long-term contracted assets, focusing on clean energy solutions such as renewable generation facilities, battery storage projects, and electric transmission facilities. NextEra Energy Resources, a subsidiary of NextEra, has the largest portfolio of battery storage projects in the U.S. However, NextEra's involvement in BESS is relatively smaller compared to their core businesses.

Vistra Corp engages in electricity generation, wholesale energy trading, commodity risk management, fuel production, and logistics, serving around 3.5 million customers. With a generation capacity of approximately 37,000 MWs, its portfolio includes natural gas, nuclear, coal, solar, and battery energy storage facilities.

Vistra Corp is currently second-place in the deployment of BESS in the U.S. However, involvement in BESS storage is small compared to their core businesses. Their investments and initiatives suggest they are actively seeking a larger share of the energy storage market.

ESS Tech is a global energy storage company specializing in the design and production of iron flow batteries tailored for commercial and utility-scale energy storage applications. The company provides a range of energy storage products, including the Energy Warehouse, designed for behind-the-meter applications, and the Energy Center, serving as a front-of-the-meter solution.

ESS Tech while not the largest player in terms of absolute market share, ESS Tech has a strong focus on the energy storage market with 100 percent of its business dedicated to it. This specialization, coupled with their innovative iron flow battery technology, suggests they have a significant market share within that specific segment.

Eos Energy Enterprises, Inc. designs, manufactures, and markets zinc-based energy storage solutions for various markets, including utility, commercial, industrial, and microgrid sectors in the U.S. Its key product is the Eos Znyth DC system, a battery offering an alternative to lithium-ion batteries.

Eos Energy Enterprises focuses solely on energy storage solutions. Their zinc-based technology offers an alternative to Li-ion batteries, potentially giving them a significant share within the niche market segment of zinc-based energy storage.

Diversified Energy Players with BESS Initiatives

Tesla, Inc. is involved in designing, developing, manufacturing, leasing, and selling EVs, as well as energy generation and storage systems globally. Operating in Automotive and Energy Generation and Storage segments, Tesla's Energy segment focuses on designing, manufacturing, installing, selling, and leasing solar energy generation and energy storage products for residential, commercial, industrial customers, and utilities.

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[162] "Top Largest Companies in the Energy Sector List | Screener - Yahoo Finance."

Tesla's powerwall is a well-known home BESS solution, holding a significant market share within that segment. However, their overall share in the broader energy storage market may be smaller compared to companies with a more focused business model.

Energy Vault Holdings, Inc. specializes in the development and sale of energy storage solutions. The company provides a range of systems, including BESS for shorter-duration needs, gravity energy storage systems, such as the EVx solution, green hydrogen energy storage systems, hybrid energy storage systems, and an energy management software platform. This platform is designed to coordinate the management of diverse storage mediums, offering a comprehensive solution for energy storage requirements.

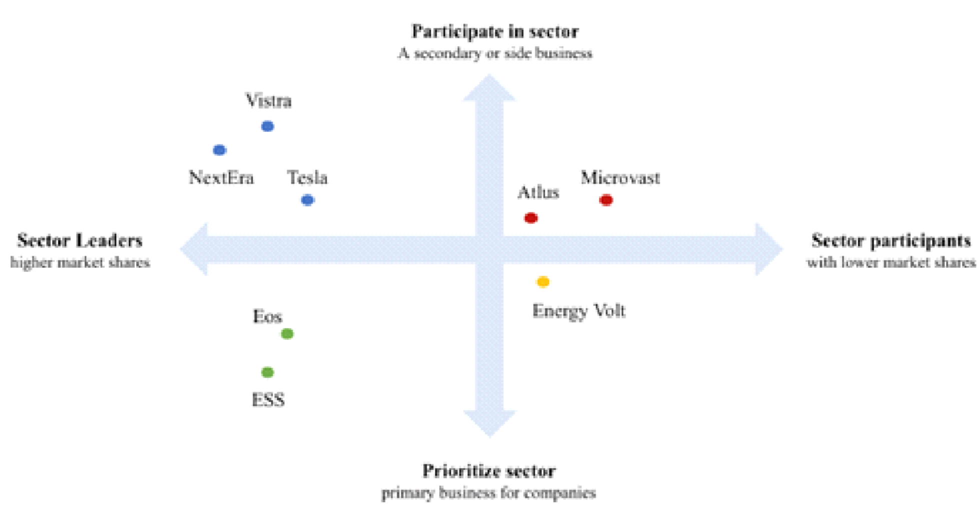
Energy Vault Holdings has the potential to capture a significant portion of the market within the gravity-based energy storage technology segment. Their partnerships and growing project portfolio indicate their presence is growing in the overall energy storage market.

Emerging Players in Energy Storage Technology

Altus Power, Inc. is a clean electrification company that focuses on the development, ownership, construction, and operation of photovoltaic solar energy generation and storage systems. The company caters to a diverse range of clients, including commercial, industrial, public sector, and community solar customers. Altus Power's primary focus lies in solar energy generation, their increasing involvement in solar-plus-storage solutions indicates they are actively capturing a share of the market for combined energy solutions.

Microvast Holdings, Inc. designs, develops and manufactures battery systems for EVs and energy storage applications globally. The company provides diverse cell chemistries, including lithium titanate oxide, lithium iron phosphate, and nickel manganese cobalt. Additionally, Microvast designs develops, and manufactures battery components like cathodes, anodes, electrolytes, and separators. Beyond EVs, the company extends its expertise to offer battery solutions for commercial vehicles and energy storage systems. Microvast Holdings provides diverse battery systems for EVs and energy storage applications, Microvast has a presence in several market segments. However, their share may be more substantial within the specific niche of lithium titanate oxide and lithium iron phosphate batteries.

Figure 34. Matrix evaluation of key players for BESS



Source: Columbia SIPA

2.4 Commercial clean vehicles

2.4.1 Importance of commercial clean vehicles for the energy transition

The EV truck and bus industry is a rapidly evolving sector that is gaining momentum due to its potential to reduce emissions, improve air quality, and save costs. Electric buses and trucks are becoming increasingly competitive, with a growing focus on electrifying medium and HDVs. The industry is being promoted by various associations and organizations, with a strong emphasis on public and private investment, as well as electric utility support for electric trucks and buses[163]. Electric road freight transportation, including trucks, is a crucial component of the industry, with governments worldwide placing a strong focus on the transition to electric road freight vehicles. The penetration of electric trucks into the global medium-duty vehicle (MDV) and HDV market is projected to reach 9.4 percent by 2030, highlighting the significant potential for growth and adoption in this segment[164]. Private sector demand for zero-emission commercial vehicles is also amplifying market signals for OEMs to develop EVs.

The importance of electric trucks and buses in the context of industrial activities is significant, with several key factors contributing to their growing relevance:

- Environmental Impact: Electric buses and trucks offer a substantial reduction in emissions, contributing to improved air quality and reduced GHG emissions. The transition to EVs aligns with efforts to "greenize" industrial activities, promoting sustainability and environmental stewardship.
- Economic Benefits: The adoption of electric buses and trucks presents major economic opportunities. EVs are becoming increasingly competitive on a total-cost-of-ownership basis, offering potential cost savings in fuel and maintenance. Additionally, the electric truck and bus industry is creating new job opportunities, contributing to economic growth and development.
- Energy Efficiency: Electric trucks and buses are far more energy-efficient than their diesel and natural gas counterparts, offering up to four times greater efficiency. This increased efficiency can lead to significant savings in fuel costs, making EVs an attractive option for industrial transportation needs.
- Technological Readiness: The technology for electric trucks and buses is readily available and capable of meeting the operational demands of industrial activities. EVs can accelerate, climb hills, and perform as well as or better than traditional vehicles, while also offering quieter operation.
- Global Impact: The electrification of road transport, particularly in emerging and developing economies, can have a substantial impact on reducing emissions and promoting sustainable transportation. Policy-led deployment and incentives can help kickstart the transition to electric buses and trucks, furthering the global effort to mitigate climate change.

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[163] Nigro, Nick. "Medium- and Heavy-Duty Vehicle Electrification." Atlas EV Hub, www.atlasevhub.com/materials/medium-and-heavy-duty-vehicle-electrification/. Accessed 11 Dec. 2023.

[164] An Introduction to Electric Road Freight Vehicles." Evenergi, 6 July 2021, www.evenergi.com/an-introduction-to-electric-road-freight-vehicles/.

2.4.2 Development trend of commercial clean vehicles prior to IRA

The development trend of EV trucks and EV buses has been gaining momentum in recent years. The availability of electric HDV models has been expanding, involving manufacturers such as Daimler, MAN, Renault, Scania, and Volvo. Several leading companies are at the forefront of electric bus manufacturing, including TEMSA, Solaris Bus & Coach, Volvo Group, and Tata Motors, each making significant strides in the development and delivery of electric buses.[165].

While buses were the earliest and most successful case of electrification in the HDV market, the growing demand for electric trucks is pushing manufacturers to broaden their product lines[166]. The trend of new model development has shifted from buses to MDV and HDV, with more than half of the 220 models that became available in 2022 being trucks[167]. China has been at the forefront of production and sales of electric trucks and buses, representing a significant portion of global sales.

The electric truck and bus market has seen promising signs of reaching cost and performance metrics that make them increasingly competitive without government support[168]. The average declared range of electric trucks produced in China exceeded 300 km, and that of electric buses reached 400 km, with a growing number of electric buses having ranges that enable intercity operations2. Despite a reduction in subsidies, electric bus and truck sales began increasing in 2021 and grew again in 2022, indicating a positive trajectory for the industry[169].

The development of the EV truck and bus industry has the potential to contribute to demand for labor in areas such as the design and development of EV models, the production of batteries, and the installation and maintenance of charging infrastructure[170]. This trend is expected to create high-quality American jobs, and federal policymakers are being urged to invest in domestic EV production and deployment to support these jobs[171].

2.4.3 IRA-related incentives for commercial clean vehicles

The IRA includes several provisions aimed at encouraging the electrification of MDVs and HDVs, including EV trucks and EV buses. One of the key provisions is the tax credits for the purchase of electric trucks and the installation of charging infrastructure. The IRA offers a purchase tax credit of up to $40,000 for the largest vehicles and a tax credit of up to $100,000 per charging station, which makes owning an electric truck cheaper than owning a diesel one in most use cases. These tax credits are designed to incentivize fleet operators to start planning for the transition to electric

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[165] Swallow, Tom. "Top 10: Electric Bus Companies." Evmagazine.com, 6 Sept. 2023, evmagazine.com/top10/top-10-electric-bus-companies.

[166] IEA. "Trends and Developments in Electric Vehicle Markets – Global EV Outlook 2021 – Analysis." Iea, 2021, www.iea.org/reports/global-ev-outlook-2021/trends-and-developments-in-electric-vehicle-markets.

[167] "Trends in Electric Heavy-Duty Vehicles – Global EV Outlook 2023 – Analysis." IEA, www.iea.org/reports/global-ev-outlook-2023/trends-in-electric-heavy-duty-vehicles.

[168] Ibid

[169] Ibid

[170] Colato , Javier , and Lindsey Ice. "Charging into the Future: The Transition to Electric Vehicles." U.S. Bureau of Labor Statistics, Feb. 2023, www.bls.gov/opub/btn/volume-12/charging-into-the-future-the-transition-to-electric-vehicles.htm.

[171] "Electric Vehicles: A Win for American Workers." Center for American Progress, https://www.americanprogress.org/article/electric-vehicles-win-american-workers/.

trucks and buses, and to ensure that manufacturers, utilities, and regulators play their part in facilitating the adoption of EVs[172]

The IRA's tax credits for electric trucks and buses are expected to have a significant impact on the market. It is projected that the tax credits could double or even triple the share of electrified trucks and vans used in fleets by 2030 compared to business as usual, leading to a substantial increase in electric truck sales3. Additionally, the law allocates funds to states, municipalities, Indian tribes, or non-profit school transportation associations to replace class 6 and 7 HDVs with clean EVs, providing support for the electrification of medium and HDVs. Overall, the IRA's provisions for EV trucks and EV buses are seen as a game changer, driving the transition to electric trucks and buses and making the case for zero-emissions trucks even stronger[173].

2.4.4 Recent announcements and key players for commercial clean vehicles

In the dynamic landscape of the EV truck industry, ***Tesla, Inc.'s*** highly anticipated Cybertruck is poised for a commercial launch in the near term, garnering significant attention and anticipation. Recent data from a crowd-sourced online reservation tracker indicates that net reservations for the Cybertruck have surpassed the two million mark, signaling strong market interest

Originally announced by Tesla CEO Elon Musk in late 2019, the Cybertruck's launch has experienced delays, attributed to the COVID-19 pandemic, along with geopolitical and economic uncertainties, and the challenge of designing something so innovative. Despite these setbacks, public interest escalated steadily and by May 2021, reservations had reached the one million milestone. As of late July 2023, reports from Benzinga indicated that reservations had climbed to 1,943,876 units[174]. On November 30, 2023, Tesla delivered Cybertruck, at the company's headquarters in Austin, Texas. During the event, customers took delivery of Cybertrucks, and Tesla revealed details about the vehicle[175]. Musk’s recent updates on the model indicate that the Cybertruck is not expected to significantly affect Tesla's finances until 2025, projecting the EV truck to occupy a minor fraction of the company's overall delivery volume in 2024

For other players, ***Rivian*** and ***Lucid*** have emerged as significant competitors in the EV truck market, a domain traditionally dominated by established firms like Tesla[176]. These startups have gained substantial traction through major investments and strategic partnerships. Rivian, with support from Amazon and Ford, has introduced the R1T, an all-electric pickup that garnered the title of Motor Trend's Truck of the Year. Lucid, backed by the Saudi Arabian wealth fund, has focused on high-end luxury EVs, exemplified by its Air sedan, which was named Motor Trend's Car of the Year.

[172] Mills, Ryan. “The Inflation Reduction Act Will Help Electrify Heavy-Duty Trucking.” RMI, 25 Aug. 2022, rmi.org/inflation-reduction-act-will-help-electrify-heavy-duty-trucking/.

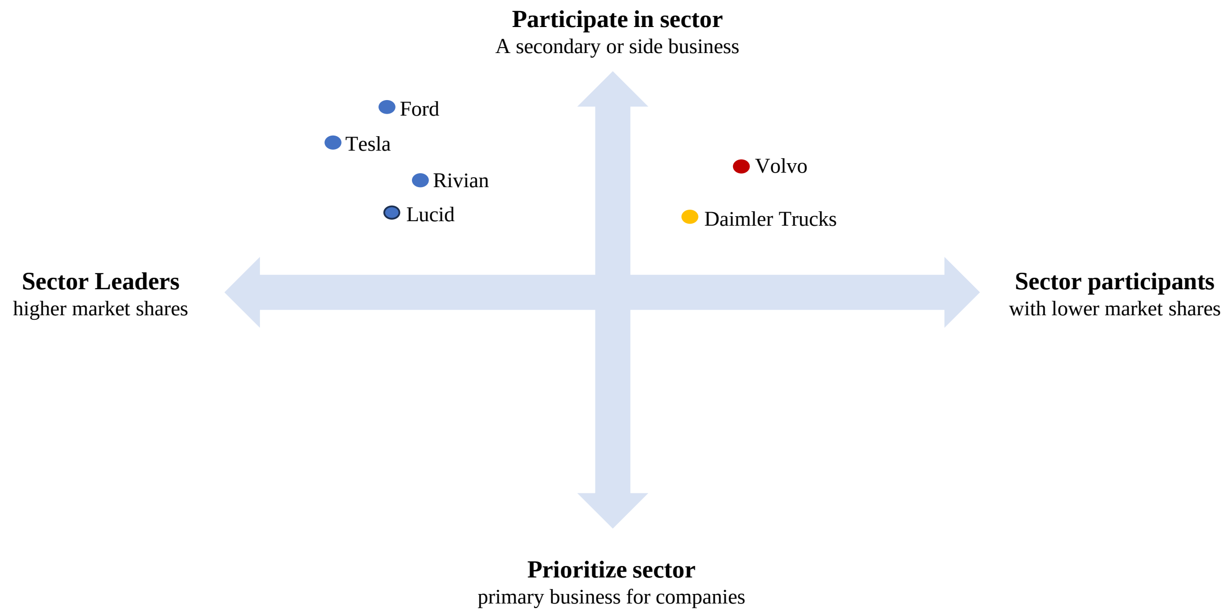
[173] Kahn, Brian. “Inflation Reduction Act Truck Tax Credits: “Game Changer” - Protocol.” Www.protocol.com, www.protocol.com/climate/ira-electric-heavy-duty-trucks. Accessed 11 Dec. 2023.

[174] Rexaline, Shanthi. “Tesla Cybertruck Reservations Swell to over 1.9M - Tesla (NASDAQ:TSLA).” Benzinga, www.benzinga.com/markets/equities/23/07/33332166/elon-musks-off-the-hook-cybertruck-demand-comment-proven-right-as-reservations-soar-to-over-1-9m. Accessed 11 Dec. 2023.

[175] “Press Releases | Tesla Investor Relations.” Ir.tesla.com, ir.tesla.com/press.

[176] “Electric Startups Lucid Air and Rivian Are Snapping up All the Awards This Year.” NBC News, www.nbcnews.com/business/autos/electric-startups-lucid-air-rivian-are-snapping-awards-year-rcna8573.

Figure 35. Matrix evaluation of key players for clean commercial vehicles



Source: Columbia SIPA

2.5 Biofuels

2.5.1 Importance of biofuels for the energy transition

Biofuels are derived from organic biomass materials as feedstocks and represent a crucial component of the transition towards a more sustainable energy landscape. Encompassing a diverse range of liquid and gaseous fuels, they are primarily used as transportation fuels, with applications in heating and electricity generation. The terminology associated with biofuels can vary, reflecting their diverse origins and applications, with prefixes like "bio," and descriptors such as "advanced," "renewable," and "sustainable" used to differentiate types within government programs and industry branding efforts.

The U.S. Energy Information Administration (EIA) classifies biofuels into four primary categories:[177]

- Ethanol: An alcohol derived from fermenting corn, sorghum, barley, sugar cane or sugar beets that is blended with petroleum gasoline.
- Biodiesel: Derived from organic oils such as vegetable oil and animal fats, it is typically blended with petroleum diesel.
- Renewable Diesel: Derived from the same feedstocks as biodiesel the production process for renewable diesel sufficiently removes impurities to make this fuel chemically akin to petroleum diesel, suitable for drop-in use or blending, exhibiting incremental growth in production and consumption.

177 U.S. Energy Information Administration. "Biofuels Explained." Energy Explained, https://www.eia.gov/energyexplained/biofuels/.

- Other Biofuels: Encompassing a spectrum of emerging fuels derived from biomass, including renewable heating oil and gaseous biofuels like biogas or renewable natural gas (RNG) which contribute to the expanding biofuel landscape.

Biofuels present a promising alternative to fossil fuels in terms of environmental impact. Pure ethanol and biodiesel are both nontoxic and biodegradable, offering a safer spillage profile compared to their petroleum counterparts. While biofuels are flammable, similar to fossil fuels, prudent transportation practices mitigate associated risks.

In terms of combustion emissions, biofuels tend to produce fewer particulates, sulfur dioxide, and air toxins. Moreover, biofuel-petroleum blends generally yield lower emissions than non-biofuel-containing fuels. Although biodiesel combustion may lead to slightly elevated nitrogen oxide levels relative to petroleum diesel, the overall environmental benefits remain significant.

Biofuels mitigate climate change by displacing fossil fuels, but the impact of biofuel use on net carbon emissions hinges on production methods and the inclusion of emissions linked to the particular feedstock. Growing crops for ethanol and other biofuel production has spurred debate, with concerns raised over diverting resources from food production. Notably, large swaths of natural vegetation and forests have been cleared for biodiesel feedstock cultivation, emphasizing the need for sustainable sourcing practices.

Efforts are underway to develop biofuels with lower energy input and reduced environmental footprint. Cellulosic biomass, including native grasses, fast-growing trees, and waste materials, holds promise as a more sustainable feedstock. However, technical and economic challenges currently impede large-scale commercial production.

As biogases such as RNG are derived from purifying waste from landfills, cow manure, wastewater treatment and other sources of organic waste, its feedstock does not generate incremental carbon. RNG production is not innovative but is limited by the need for closely-sited feedstock sources. As RNG is largely methane, it has the advantage of being a direct substitute for fossil derived natural gas for generating electricity and as a compressed gas transportation fuel.[178]

2.5.2 Development trend of biofuels prior to IRA

As of January 2023, the U.S. has witnessed a transformative surge in the production capacity of renewable diesel and other biofuels, surpassing biodiesel for the first time. This growth is driven by escalating targets set by state and federal renewable fuel programs, coupled with the renewal of biomass-based diesel tax credits. The broader biofuels spectrum in the U.S., encompassing renewable diesel, biodiesel, ethanol, and other biofuels, surged to a total production capacity of 23 billion gallons per year in January 2023.[179] This represents a 6 percent increase from the preceding year.[180] Fuel ethanol takes the lead, accounting for 78 percent of the nation's biofuel production

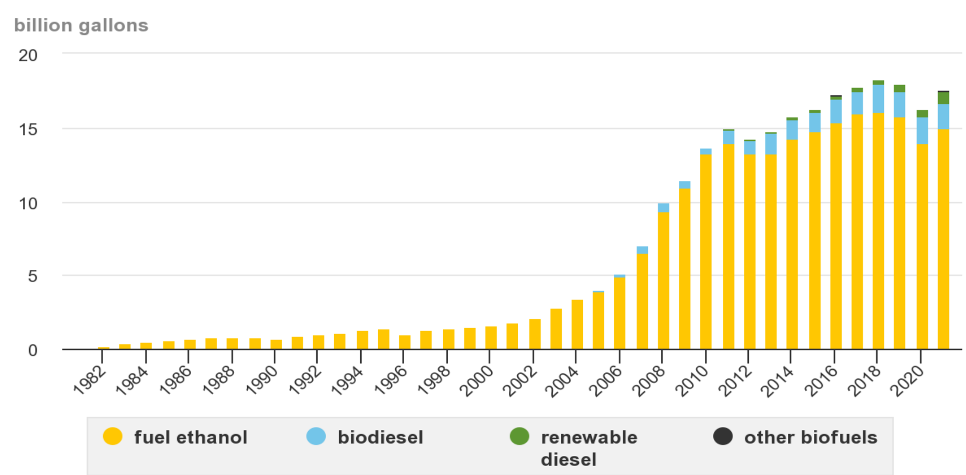
[178] "Trash to Treasure: Midstream and Renewable Natural Gas." ETF Trends, https://www.etftrends.com/energy-infrastructure-channel/trash-to-treasure-midstream-and-renewable-natural-gas.
[179] U.S. Energy Information Administration. "Today in Energy." U.S. Energy Information Administration, https://www.eia.gov/todayinenergy/detail.php?id=60281/.
[180] Ibid

capacity, followed by renewable diesel and other biofuels at 13 percent, and biodiesel at 9 percent.[181]

Renewable diesel stands out as a fuel with chemical equivalence to petroleum diesel, exhibiting nearly identical performance characteristics. This distinction sets it apart from biodiesel, which differs chemically from its petroleum-based counterpart. This similarity in performance positions renewable diesel as a pivotal player in the transition towards sustainable transportation fuels. Between January 2022 and January 2023, the production capacity for renewable diesel and other biofuels escalated by 1.25 billion gallons per year.[182] This equates to a 71 percent increase from the previous year, underscoring the accelerated momentum in the sector.[183] Biodiesel, once a significant player, now represents the smallest share of U.S. biofuels capacity. In January 2023, its capacity stood at 2.1 billion gallons per year, marking a 13 percent decline from January 2022.[184]

The Renewable Fuel Standard (RFS) program, originating in the Energy Policy Act of 2005 and subsequently expanded by the Energy Independence and Security Act of 2007 (EISA), has been a linchpin in steering the biofuel revolution. Administered by the U.S. Environmental Protection Agency (EPA), the RFS program establishes volume requirements for various biofuel categories, each with defined GHG emissions thresholds relative to petroleum fuels. These categories encompass conventional biofuel, advanced biofuel, biomass-based diesel, and cellulosic biofuel, each necessitating specific GHG emissions reductions. The program mandates the integration of renewable fuels into transportation fuel, with targets escalating to about 45 billion gallons by 2025.[185]

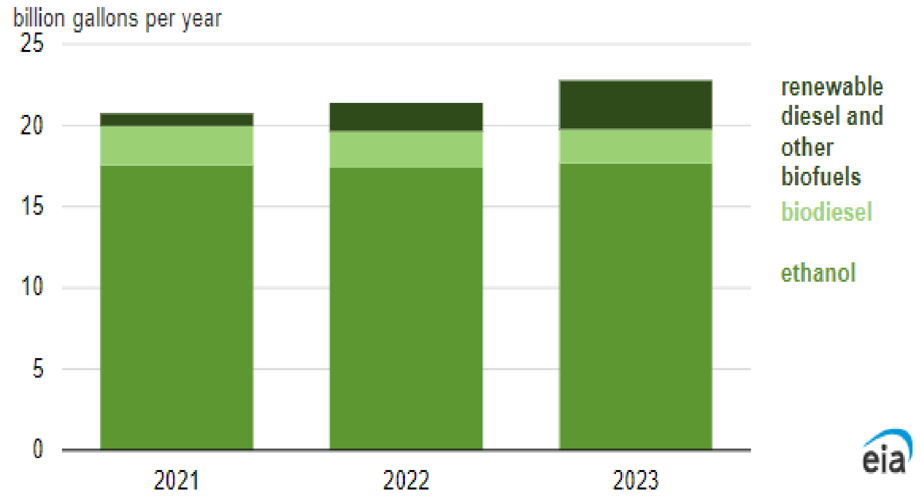
Figure 36. U.S. biofuels production by major type, 1981-2021



Source: U.S. Energy Information Administration

[181] Ibid
[182] Ibid
[183] Ibid
[184] Ibid
[185] U.S. Department of Agriculture, Economic Research Service. "Global Demand for Fuel Ethanol Through 2030."

Figure 37. Annual U.S. biofuels production capacity as of Jan 1, 2021-2023



Source: U.S. Energy Information Administration

Biofuel consumption in the U.S. is projected to increase by 11 percent, reaching 70,600 million liters per year (MLPY) by 2027.[186] This growth is primarily attributed to the rising demand for renewable diesel. Several key drivers contribute to this increase, including the IRA, the Renewable Fuel Standard, and state-level low-carbon fuel standards. It's important to note that while these factors promote the growth of renewable diesel, they displace biodiesel whose demand and production are expected to decline by 24 percent in 2027 due to a combination of factors. Competition for the same feedstocks, such as vegetable and waste and residue oils, places pressure on bio-oil and fat availability. Policy support in the U.S. is more favorable for renewable diesel which receives higher credits in the Renewable Fuel Standard. Moreover, renewable diesel can be blended at higher levels and produced in retrofitted refineries, contributing to reduced biodiesel demand.

The future trajectory of U.S. fuel ethanol consumption is anticipated to exhibit incremental growth over the next decade, with projections indicating a 5.1 percent increase from 13.9 billion gallons in 2021 to 14.7 billion gallons in 2030.[187] Net exports are expected to surge, reaching 2.1 billion gallons in 2030, reflecting a substantial rise from preceding years.[188]

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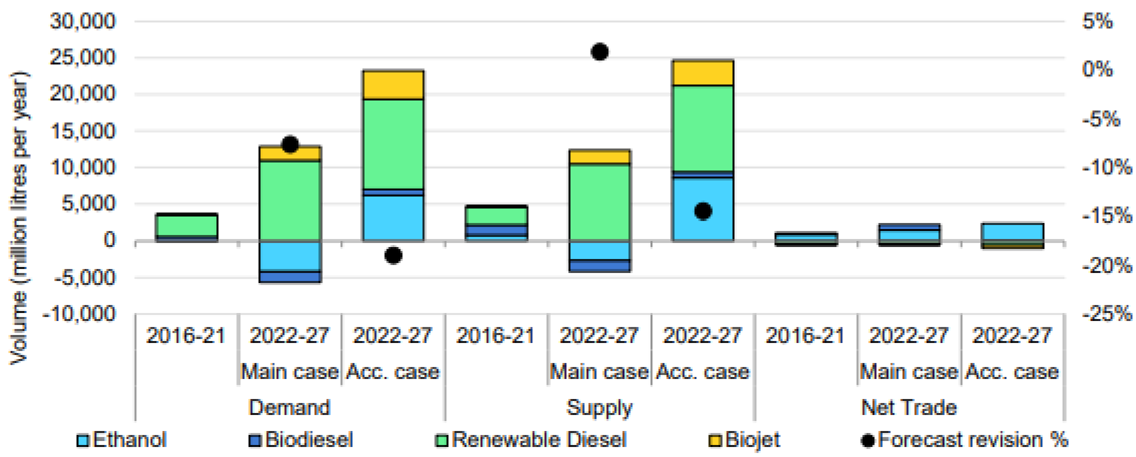
[186] International Energy Agency, "Renewables 2022: Analysis and forecast to 2027," January 2023.

[187] U.S. Department of Agriculture, Economic Research Service. "Global Demand for Fuel Ethanol Through 2030.", February 2023.

[188] Ibid

Figure 38. U.S. five-year biofuel growth, main and accelerated cases, 2016-2027



Source: International Energy Agency

2.5.3 IRA-related incentives for biofuels

The IRA earmarks $500 million in grant funding, competitively accessible for projects geared towards augmenting the sale and utilization of biofuels through vital infrastructure enhancements. These projects, with a focus on blending, storing, supplying, or distributing biofuels derived from agricultural feedstocks, are poised to facilitate the introduction of higher biofuel blends into the market. These grants will cover expenses for the installation or upgrade of fuel dispensers, storage tanks, and associated equipment, essential for the dissemination of higher blends of ethanol and biodiesel.

In addition, the legislation extends the critical $1/gallon tax credit for biodiesel, renewable diesel, and alternative fuels through 2024. The IRA further outlines a forward-looking initiative, introducing a Clean Fuel Production Credit (CFPC) for the years 2025 through 2027. This credit, applicable to all low-carbon fuels, is set at 20 cents/gallon for on-road transportation with a potential to receive up to a $1/gallon credit.[189]

The IRA also expanded the scope of facilities eligible for an ITC to include "qualified biogas property" (section 48). Prior to the IRA, using RNG to generate electricity generated PTCs based on the MWhs of power produced. Post IRA, the capital costs involved in recovering landfill gas or other equipment such as anaerobic digesters involved in biogas production can be subsidized by an ITC whether or not electricity is being produced from the RNG. This ITC could amount to 30 percent of qualified costs of the biogas production equipment if prevailing wage requirements are met with 10 percent adders possible if targeted U.S. content and siting were present. This capital subsidy is expected to accelerate the development of RNG projects.

The EPA is designated additional resources under the IRA to execute specific tasks integral to its annual responsibility of determining the requisite volume of renewable fuel blending with gasoline and diesel as per the RFS program. An allocation of $5 million has been set for the development

[189] H.R. 812 - 118th Congress (2023-2024): Inflation Reduction Act of 2023, H.R. 812, 118th Cong. (2023)

of tests and protocols, analysis for regular updates to regulations, and evaluation of transportation fuels' impacts on disadvantaged communities.[190]

Table 8. IRA policy incentives for biofuel production

Name of subsidy	Incentives for biodiesel, renewable diesel, and alternative fuels	Clean fuel production credit (PTC)
Synopsis	Extends tax credit for biodiesel, renewable diesel, and alternative fuels	▪ Creates a tax credit for domestic clean fuel production ▪ Credit calculated as the applicable amount per gallon multiplied by the emissions factor of the fuel
Maximum credit rate	▪ $0.50 per gallon for alternative fuels ▪ $1 - $1.10 per gallon for renewable/biodiesel	▪ $1.00 per gallon for non-aviation fuel*
Claim period	Extends credit through 12/31/2024	Starts in 2025
Qualifying fuel	biodiesel, renewable diesel, and alternative fuels	Only transportation fuels that have emissions rates ≤ 50 kg CO2e per MMBtu

*NB: *The base credit for transportation fuel at a qualified facility is 20 cents/gal if wage and apprenticeship requirements are not met, and $1/gal if they are fulfilled*

Source: H.R. 812 - 118th Congress (2023-2024): Inflation Reduction Act of 2023, H.R. 812, 118th Cong. (2023)

Carbon Capture, Utilization, and Storage Incentives

While the IRA offers support for infrastructure to boost blending rates, the long-term approval for year-round 15 percent ethanol blending remains uncertain. Nonetheless, ethanol producers can still benefit from the IRA by leveraging the carbon sequestration credit to reduce emissions or by claiming the CFPC for low-emission fuels.

As carbon removal is part of the ethanol production process, producers also stand to benefit from the IRA's provisions concerning CCUS. These technologies help reduce the life cycle carbon intensity of biofuels, consequently enhancing its value in low-carbon markets. The law extends and expands the tax credit for CCUS, commonly known as the 45Q tax credit, offering substantial incentives for projects initiated between 2023 and 2032. Under the new law, the value of the credit for carbon sequestration has been raised to $85 per metric ton (mt), while utilization of captured carbon oxide earns a credit of $60 per mt.[191] These rates are contingent on compliance with prevailing wage and apprenticeship standards. If these requirements are not met, the credits are reduced by 80 percent.[192] Furthermore, the law has adjusted the minimum volume thresholds for

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[190] "Biofuels get boost from tax credits, infrastructure funding in surprise US Senate budget proposal," S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/biofuels. Accessed November 2023.

[191] "Inflation Reduction Act charts a new course for US biofuels industry," S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/en/market-insights/blogs/agriculture/090822-ira-inflation-reduction-act-us-biofuels. Accessed November 2023.

[192] Ibid

eligibility. Previously, an ethanol plant needed to emit over 100,000 mt/year of carbon oxide to qualify, but now the threshold is lowered to 12,500 mt/year.[193]

At present, there are only around a dozen operational commercial-scale CCUS projects in the U.S.[194] These encompass ethanol plants, fertilizer facilities, and natural gas processing plants. The feasibility of these projects' hinges on factors such as the extent to which the increased tax credit of $85 per metric ton covers associated costs. Cost considerations vary widely based on factors like the concentration of captured CO_2. Estimates indicate that carbon capture expenses range from $12 to $30 per ton for ethanol facilities[195]. Additional expenses for transportation and storage vary from $3 to $40 per ton, contingent on regional factors.[196]

In addition, regulators in North and South Dakota have dealt a setback to the development of ethanol plants with carbon capture, rejecting permit applications from Summit Carbon Solutions.[197] The applications sought to construct a pipeline spanning over 2,000 miles connecting Iowa, North Dakota, South Dakota, Nebraska, and Minnesota for transporting captured CO_2 from ethanol facilities to underground storage sites. These decisions highlight regulatory hurdles that could hinder the progress of ethanol plants with carbon capture in the region. Another application for a CO_2 pipeline from Navigator CO_2 Ventures was also denied on September 7, 2023, further underscoring the challenges faced by such projects.

2.5.4 Recent announcements and key players for biofuel production

In the wake of the IRA, significant strides have been made in the biofuels sector, with several key players announcing noteworthy advancements:

In September 2023, ***Strategic Biofuels***, a private enterprise, achieved a significant milestone with its subsidiary, Louisiana Green Fuels (LGF), receiving an Air Permit from the Louisiana Department of Environmental Quality. The LGF project, classified as "synthetic minor," is committed to stringent adherence to both state and federal regulations, including robust air quality standards. This pioneering project integrates a biorefinery, green energy power plant, and carbon sequestration complex. This integrated approach has demonstrated an impressive 70 percent reduction in emissions compared to independent operation.[198]

A joint venture named One Carbon Partnership LP, composed of Vault 44.01 Inc. and ***Cardinal Ethanol LLC,*** sought regulatory approval from the EPA for an underground CO_2 storage project in Indiana's Randolph County in January this year.[199] The proposal involves drilling a Class VI well for CO_2 injection, with the EPA's response pending. This initiative is part of a broader trend in the Midwest, with several developers planning pipelines to transport CO_2 emissions from

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[193] Ibid

[194] "Why the Carbon Capture Subsidies in the Climate Bill Are Good News for Emissions." Technology Review, 25 Aug. 2022, https://www.technologyreview.com/2022/08/25/1058591/why-the-carbon-capture-subsidies-in-the-climate-bill-are-good-news-for-emissions/.

[195] Ibid

[196] Ibid

[197] "Summit Carbon Solutions." Reuters, https://www.reuters.com/business/energy/summit-carbon-solutions.

[198] "Clean Fuels." Hydrocarbon Engineering, 22 Sept. 2023, https://www.hydrocarbonengineering.com/clean-fuels/22092023/.

[199] "4th developer seeks to capture, store carbon from ethanol plants in US Midwest," S&P Global Commodity Insights. https://www.capitaliq.spglobal.com/apisv3/ Accessed November 2023

ethanol plants for storage. The recent expansion of federal subsidies for carbon capture technology under the IRA has accelerated such projects, creating a backlog of permit applications at the EPA.

Aemetis Inc., an RNG and renewable fuels company, recently concluded what may among the first IRA tax credit transfer, selling $53 million in Section 48 ITC generated by its subsidiary Aemetis Biogas LLC.[200] These credits originate from biogas projects, including dairy digesters, a biogas pipeline, and an RNG production facility. Aemetis Biogas is constructing anaerobic digesters at California dairies to capture biomethane from animal waste. The project aims to capture methane from waste produced by over 150,000 cows, generating 1,650,000 MMBtu of RNG annually.[201] The RNG produced is injected into PG&E's natural gas pipeline for use in transportation fuel, contributing to a significant reduction in emissions. Aemetis plans to qualify for more than $800 million of IRA investment and PTCs in the next four years to support its various projects.[202]

Several midstream companies have made investments in companies active in the RNG sector: ***TC Energy, Enbridge, Kinder Morgan (KMI)***. KMI's analysts' day presentation in January 2023 showed a forecast of U.S. RNG production growing from 0.2BCF in 2022 to 3.23 BCF in 2050.

Table 9. Publicly listed players in biofuels industry

Sub-sector	Company	Market Capitalization (US$ billion)
Ethanol	Adecoagro S.A	1.12
	Cardinal Ethanol, LLC	0.27
	Highwater Ethanol, LLC	0.08
Biodiesel	HF Sinclair	9.4
Biogas	Shell p.l.c.	210.6
	BP p.l.c.	98.7
	Enbridge Inc.	70.84
	TC Energy Corp.	37.12
	Kinder Morgan, Inc.	36.54
	Ameresco, Inc	1.7
	FutureFuel Corp.	0.28
	Opal Fuels Inc.	0.21
Ethanol/biodiesel/ biogas	Marathon Petroleum Corp.	57.2
	Valero Energy	44.7
	Aemetis, Inc.	0.18

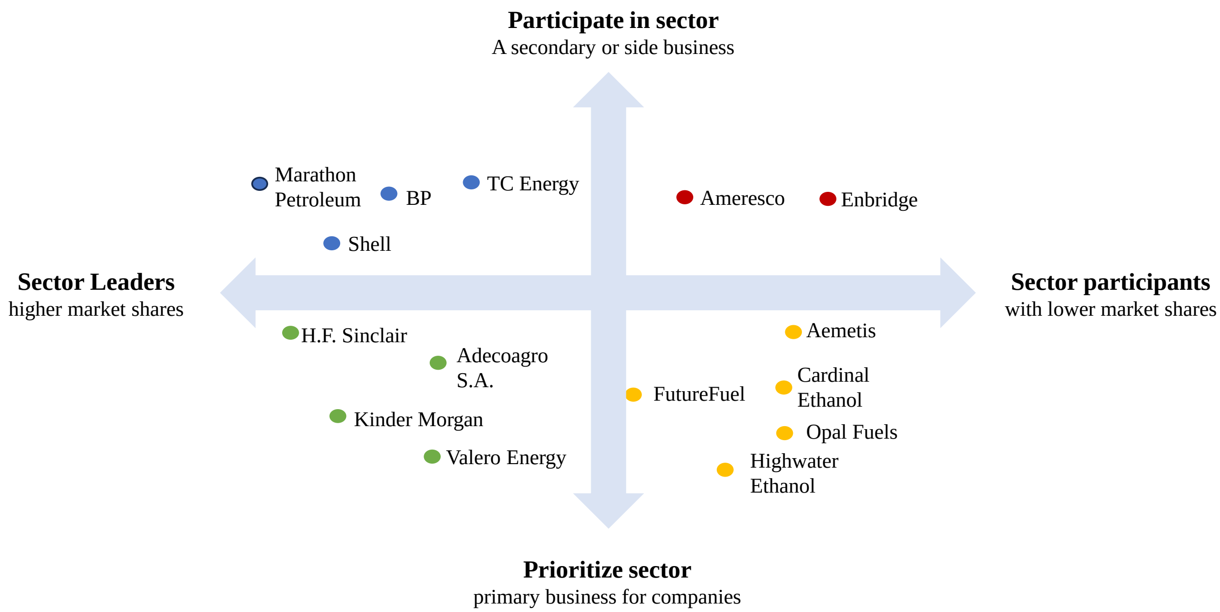
Source: S&P Global, Data accessed September 2023

[200] "Aemetis Biogas Closes $53 Million Sale of IRA Tax Credits." Biomass Magazine, https://biomassmagazine.com/articles/aemetis-biogas-closes-53-million-sale-of-ira-tax-credits

[201] Ibid

[202] Ibid

Figure 39. Matrix evaluation of key players for biofuel production



Source: Columbia SIPA

2.6 Sustainable Aviation Fuels

2.6.1 Importance of SAF for the energy transition

Decarbonizing the aviation industry is one of the biggest challenges facing the global economy, as aviation is responsible for 12 percent of transportation-related CO_2 emissions and two percent of human emissions overall.[203] Until recently, the industry attempted to minimize its environmental impact via carbon credits and offsets. However, activists argue that these credits do nothing to address the underlying material bases for climate change.[204] The alternative of developing what regulations and the market generally labels as SAF sourced from bio and synthetic fuels has, until very recently, been uneconomical due to the higher price per gallon compared to conventional fuel and the potential for costly infrastructure upgrades.[205] Furthermore, SAF has historically also been more expensive than sustainable biodiesel, encouraging renewable fuel producers to focus more on the latter.[206] As a result, the development and adoption of SAF have been hindered.

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[203] Kristi Moriarty and Derek Vardon, *Sustainable Aviation Fuel and U.S. Airport Infrastructure*, US Department of Energy Office of Energy Efficiency & Renewable Energy, 2023, 9.

[204] Kendra Pierre-Louis, "A Greenwashing Lawsuit against Delta Aims to Set a Precedent" *Bloomberg.Com*, Bloomberg, 13 June 2023, www.bloomberg.com/news/articles/2023-06-13/a-greenwashing-lawsuit-against-delta-aims-to-set-a-precedent.

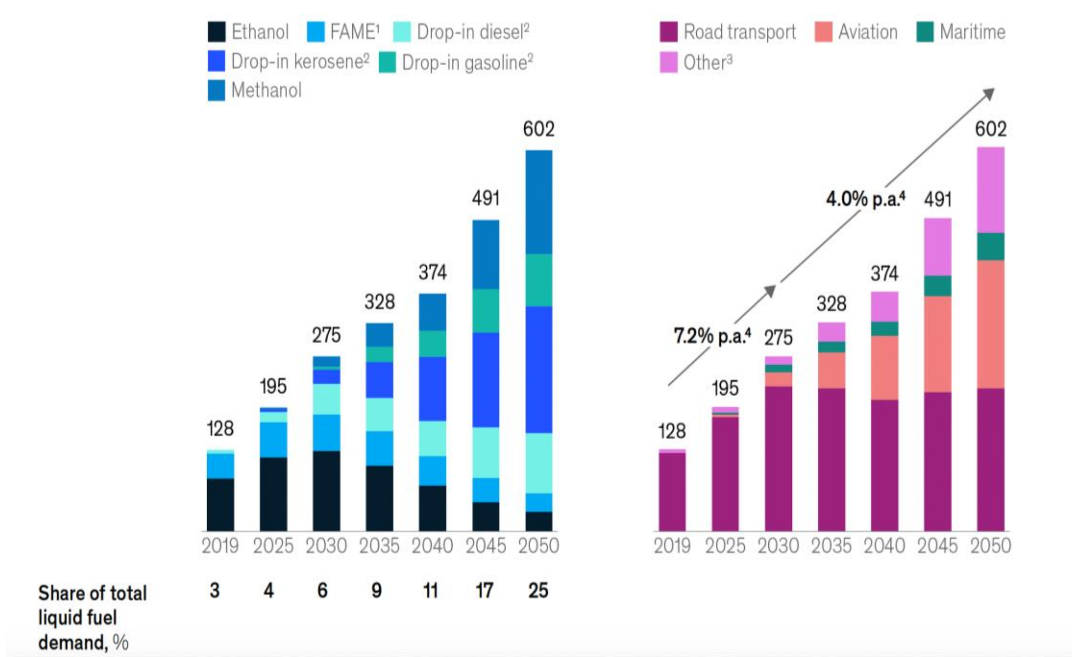
[205] United States Government Accountability Office, *Sustainable Aviation Fuel: Agencies Should Track Progress toward Ambitious Federal Goals: Report to Congressional Committees*, 2023, 13; Asim Anand. "Sustainable Aviation Fuel: Agriculture's Ticket to Redemption?" S&P Global Commodity Insights, 21 Sept. 2023, www.spglobal.com/commodityinsights/en/market-insights/blogs/agriculture/092123-sustainable-aviation-fuel-agricultures-ticket-to-redemption.Accessed 14 Nov. 2023.

[206] Dania Saadi, "US-Based United Airlines Expects Inflation Reduction Act to Spur More SAF Output," *S&P Global Commodity Insights*, 29 Mar. 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-

However, the passage of the IRA in August 2022 engendered the inclusion of SAF-specific tax credits. This has made SAF competitive with conventional jet fuel and other renewables. Transitioning to SAF is now seen as the primary way of decarbonizing the aviation industry, and multiple companies, governments, and trade groups have set 2050 as a goal for moving away from petroleum-based fuel entirely.[207] This is in line with a goal of net-zero industry emissions by 2050, and according to the International Air Transport Association (IATA), SAF production will need to reach 120 billion gallons per year - up from the roughly 80 million gallons produced in 2022—to make the transition.[208]

The Biden administration has set a goal of producing at least 35 billion gallons per year domestically by 2050, and the tax credits from the IRA are intended to stimulate the growth necessary to achieve this.[209] As a recent analysis by McKinsey & Company shows (pictured in **Figure 40**), the industry will require a fundamental overhaul to meet these challenges, as the feedstock necessary to produce fuel for a SAF-exclusive airline industry currently does not exist. This offers the opportunity for investment in previously distressed areas. However, a better look at current trends in the field of SAF is warranted.

Figure 40. Sustainable fuel demand by carrier (left) and sector (right)



Source: McKinsey & Company

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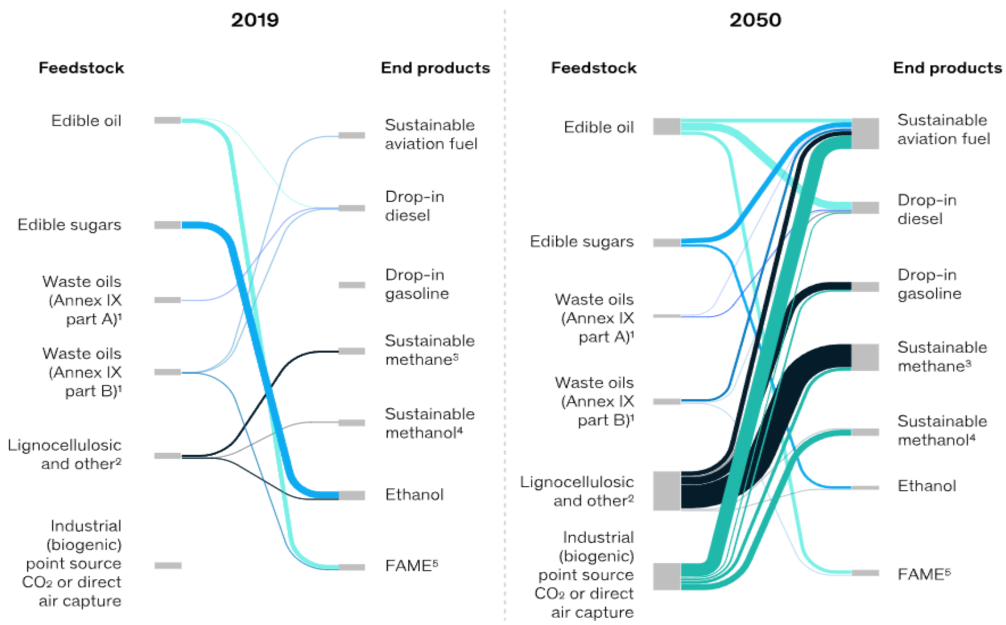
transition/032923-us-based-united-airlines-expects-inflation-reduction-act-to-spur-more-saf-output. Accessed 14 Nov. 2023.

[207] Ibid; "Environmental Sustainability Initiatives: Southwest Airlines," Environmental Sustainability Initiatives | Southwest Airlines, www.southwest.com/citizenship/planet/, Accessed 14 Nov. 2023.

[208] Saadi, Dania. "US-Based United Airlines Expects Inflation Reduction Act to Spur More SAF Output." S&P Global Commodity Insights, 29 Mar. 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/032923-us-based-united-airlines-expects-inflation-reduction-act-to-spur-more-saf-output#:~:text=That%20initiative%20aims%20to%20boost,year%20of%20SAF%20by%202050. Accessed 14 Nov. 2023.

[209] Ibid

Figure 41. Projected feedstock to 2050



Source: Melgin[210]

2.6.2 Development trend of SAF prior to IRA

Despite historical cost and supply disadvantages to conventional jet fuel, SAF development has still been an important part of recent research and development in the aviation industry. As such, it is well-positioned to take advantage of the IRA's benefits. However, specific standards exist for what can be considered SAF and a few different ways it can be produced.

Generally, SAF must reduce lifecycle GHG emissions compared to conventional fuel, and the IRA outlines specific lifecycle reduction standards that must be met (the details of the IRA provisions are further discussed in Section 2.6.3).[211] In general, fuel must reduce emissions by 50 percent compared to conventional fuel to qualify for the credit, with additional bonuses for every percentage point above 50.[212] There are multiple ways of making SAF, and the two most relevant for this report are ethanol-to-jet and the Fischer–Tropsch power-to-liquid process. In the ethanol-to-jet process, ethanol produced from agricultural biomass is converted into jet fuel, while the Fischer–Tropsch power-to-liquid process uses available carbon from waste biomass to produce synthetic fuels.[213] Feedstock has been an important element hindering development thus far, as the previous cost of SAF has made the use of available biomass for this purpose economically unwise.

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210 Melgin, Tapio, et al. "How Traders Can Capture Value in Sustainable Fuels." McKinsey & Company, McKinsey & Company, 4 Oct. 2023, www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-traders-can-capture-value-in-sustainable-fuels. Accessed 14 Nov. 2023.

211 United States GAO, 6.

212 Jane O'Malley, "Drawbacks of Adopting a 'Similar' LCA Methodology for U.S. Sustainable Aviation Fuel (SAF)," *International Council on Clean Transportation*, 26 Sept. 2023, theicct.org/publication/drawbacks-of-adopting-similar-lca-methodology-us-saf-sept23/. Accessed 14 Nov. 2023.

213 Dan Brown, "Air France-KLM Confirms Its Strategic Cooperation with SAF Producer DG Fuels by Investing in Their SAF Production Facility in the United States," *DG Fuels*, 10 Nov. 2023, dgfuels.com/2023/11/10/air-france-klm-confirms-its-strategic-cooperation-with-saf-producer-dg-fuels-by-investing-in-their-saf-production-facility-in-the-united-states/. Accessed 14 Nov. 2023.

Alternative sources of biomass have been proposed to make up the shortfall, but some of these, such as palm oil waste, are often produced in countries with minimal land use protections, resulting in negligible lifelong emission reductions.[214]

Both processes have their advantages and drawbacks, and in both cases, the goal is SAF, which is known as "drop-in" or fungible fuel, meaning it can be used interchangeably with conventional jet fuel without needing changes to equipment or infrastructure. Whether the administration adopts a model based on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) or GHG, Regulated Emissions, and Energy Use in Technologies (GREET) will ultimately affect the bottom line of SAF producers, blenders, and purchasers because these models treat different parts of the product life cycle differently.[215]

2.6.3 IRA-related incentives for SAF

The key provision of the IRA related to SAF is that it gives credits fo $1.25 per gallon of SAF that has been mixed, sold, or used between December 31, 2022 and January 1, 2025, if that fuel has a 50 percent reduction in lifecycle emissions, with and additional cent for each point above 50 up to a maximum of $1.75 per gallon. [216]

Figure 42. IRA policy incentives for SAF production

Reduction In Lifecycle Greenhouse Gas Emissions (%)	50% (minimum threshold)	60%	70%	80%	90%	100%
Amount of Tax Credit ($/gallon)	1.25	1.35	1.45	1.55	1.65	1.75

Source: Internal Revenue Service

Organizations can claim the credit as an excise tax claim or general business credit. The law specifies that this 50 percent reduction will be measured via CORSIA or "any similar methodology," leading to the current confusion over whether CORSIA or GREET will be applied.[217] Although the IRS and the U.S. Treasury have issued some recent guidance on certain credit features, this question has not yet been settled. Thus, the most immediate effect of the SAF credit has been to make SAF more competitive with conventional jet fuel and renewable diesel

[214] Samyak Pandey and Aditya Kondalamahanty, "APPEC: Industry Uncertain on Using Palm Oil as SAF Feedstock." S&P Global Commodity Insights, 5 Sept. 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/090523-appec-industry-uncertain-on-using-palm-oil-as-saf-feedstock. Accessed 14 Nov. 2023.

[215] Brown, Dan. "Air France-KLM Confirms Its Strategic Cooperation with SAF Producer DG Fuels by Investing in Their SAF Production Facility in the United States." DGFuels, 10 Nov. 2023, dgfuels.com/2023/11/10/air-france-klm-confirms-its-strategic-cooperation-with-saf-producer-dg-fuels-by-investing-in-their-saf-production-facility-in-the-united-states/. Accessed 14 Nov. 2023.

[216] "Sustainable Aviation Fuel Credit," *Internal Revenue Service*, 31 Jan. 2023, www.irs.gov/credits-deductions/businesses/sustainable-aviation-fuel-credit (SAF,1818), Accessed 14 Nov. 2023.

[217] O'Malley, Jane. "Drawbacks of Adopting a 'Similar' LCA Methodology for U.S. Sustainable Aviation Fuel (SAF)." International Council on Clean Transportation, 26 Sept. 2023, theicct.org/publication/drawbacks-of-adopting-similar-lca-methodology-us-saf-sept23/. Accessed 14 Nov. 2023.

and, in some cases, even more valuable.[218] This has meant immediate benefits for those companies already producing and using SAF and greater incentives for future projects.

2.6.4 Recent announcements and key players for SAF production

The passage of the IRA only accelerated existing trends in the aviation industry, and it seems likely it will continue to have an effect even after its current provisions expire in 2025, as there is already a replacement planned. The SAF Credit will be replaced by the CFPC in 2025. The calculation methodology for the CFPC should be similar to the method used for the SAF credit.[219] This demonstrates great potential for the future. However, recent times have also shown promise.

For example, in 2021, United completed a passenger flight from Chicago to Washington, DC using 100 percent SAF in one of the plane's two engines, which GE Aviation designed via its stake in CFM International.[220] Although the fuel used was "drop-in," current international standards do not permit more than 50 percent SAF to be used in a commercial flight, so the company chose to run it through a single engine in order to demonstrate the technology while staying within current safety standards effectively. As SAF becomes more widely adopted, these ratios will undoubtedly change.[221]

The passage of the IRA saw an avalanche of announcements regarding projects intending to take advantage of the SAF tax credit. Although there was some slowdown in deals over the summer, the most recent developments indicate the effects of the IRA are still being felt, even before SAF production has ramped up in earnest.[222] However, some of these projects will not be up and running until 2025, when some of the provisions in the IRA will have expired.

Valero, which is the second-largest refiner in the U.S., opted not to include SAF production capabilities in its portfolio in the past, but in January 2023, it announced its first entry into the field.[223] Together with Darling Ingredients, the refiner is adding a SAF project to its existing plant in Port Arthur, Texas.[224] This was just the first of many major production-related announcements this year.

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[218] Brandon Mulder, "Summit AG Group to Build 'world's Largest' Ethanol-Based SAF Plant in USGC." S&P Global Commodity Insights, 15 May 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/051523-summit-ag-group-to-build-worlds-largest-ethanol-based-saf-plant-in-usgc. Accessed 14 Nov. 2023.

[219] Lorch, Steven & McGinley, Elizabeth. "Treasury Department and IRS Release Guidance with Respect to the Sustainable Aviation Fuel Credit." 18 January 2023. https://bracewell.com/insights/treasury-department-and-irs-release-guidance-respect-sustainable-aviation-fuel-credit. Accessed 27 November 2023. para. 17

[220] Will Palmer, "United Flies World's First Passenger Flight on 100% Sustainable Aviation Fuel Supplying One of Its Engines," *GE News*, 2 Dec. 2021, www.ge.com/news/reports/united-flies-worlds-first-passenger-flight-on-100-sustainable-aviation-fuel-supplying-on. Accessed 14 Nov. 2023.

[221] Ibid.

[222] Thomas Washington and Robert Perkins, "Pace of SAF Deals Slacken in 2023 as Policy-Induced Frenzy Wanes," *S&P Global Commodity Insights*, 31 Aug. 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/083123-pace-of-saf-deals-slacken-in-2023-as-policy-induced-frenzy-wanes. Accessed 14 Nov. 2023.

[223] Janet McGurty "Sustainable Aviation Fuel a Winner as US Renewable Fuel Producers Embrace Inflation Reduction Act," *S&P Global Commodity Insights*, 24 Aug. 2022, www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/082422-sustainable-aviation-fuel-a-winner-as-us-renewable-fuel-producers-embrace-inflation-reduction-act. Accessed 14 Nov. 2023.

[224] "Diamond Green Diesel (DGD) Approves a Sustainable Aviation Fuel Project at Port Arthur, Texas." Valero Energy Corp, investorvalero.com/news/news-details/2023/Diamond-Green-Diesel-DGD-Approves-a-Sustainable-Aviation-Fuel-Project-at-Port-Arthur-Texas/default.aspx. Accessed 14 Nov. 2023.

The spring of 2023 saw two major announcements regarding SAF production in the U.S. In March, ***DG Fuels*** announced it would be opening a SAF plant in Louisiana by 2026, and by May, it had already sold its initial 120 million gallons/year production capacity to a number of airlines, including Air France-KLM.[225] Just a few weeks after DG Fuels announced its Louisiana plant, Summit Agricultural Group announced its intention to open its own SAF plant somewhere in the U.S. Gulf Coast region (using Honeywell's ethanol-to-jet process).[226] Summit specifically cited the SAF tax credits in the IRA as a reason for initiating the deal and plans to work up to a 250 million gallon/year capacity when it opens in 2025.[227]

In October 2023, Boeing, United, and NASA announced a new "ecoDemonstrator" joint collaboration meant to test SAF emissions and efficiency by studying it in flight. A specially outfitted Boeing 737 will fly (as in the United SAF flight) with one tank each of SAF and conventional fuel, switching between tanks in flight while being followed by one of NASA's "Airborne Science Labs" made from a Douglas DC-8.[228] The project will study a number of features of SAF, but one of the most important will be its effect on aircraft contrails, one of the most immediate ways air travel contributes to climate change on top of the wider lifecycle effects.[229] On November 13th of 2023, Boeing also announced a partnership with synthetic fuel producer Zero Petroleum to accelerate testing of SAF produced using the Fischer–Tropsch power-to-liquid process.[230] Although the plans for the project call for a research center to be set up in the UK and it was announced at the Dubai Air Show (in part to pitch synthetic SAF as an alternative in a region without reliable feedstock), it is worth mentioning as part of the larger trend this year because it indicates the degree to which the IRA is part of a wider move toward SAF globally.

Potential for New Investment and Key Players

Many of the most likely opportunities for investment created because of the IRA's effect on the SAF industry have already been mentioned in this report. Still, not all these opportunities are created equally, as there remain different levels of risk at different stages of the pipeline. Of the publicly listed manufacturers, ***Boeing*** and ***Rolls-Royce*** have both demonstrated the successful development of SAF technologies and, perhaps more importantly, continued to partner with government stakeholders, giving their projects an attractive degree of stability. Furthermore, of all the major carriers, ***United*** is most directly invested in SAF already, consuming up to 49 percent of

[225] Brown, Dan. "Air France-KLM Confirms Its Strategic Cooperation with SAF Producer DG Fuels by Investing in Their SAF Production Facility in the United States." DGFuels, 10 Nov. 2023, dgfuels.com/2023/11/10/air-france-klm-confirms-its-strategic-cooperation-with-saf-producer-dg-fuels-by-investing-in-their-saf-production-facility-in-the-united-states/. Accessed 14 Nov. 2023.

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[228] Elisa Hahn, "Boeing, NASA, United Airlines to Test SAF Benefits with Air-to-Air Flights," *Boeing*, 12 Oct. 2023, boeing.mediaroom.com/2023-10-12-Boeing,-NASA,-United-Airlines-To-Test-SAF-Benefits-with-Air-to-Air-Flight. Accessed 14 Nov. 2023.

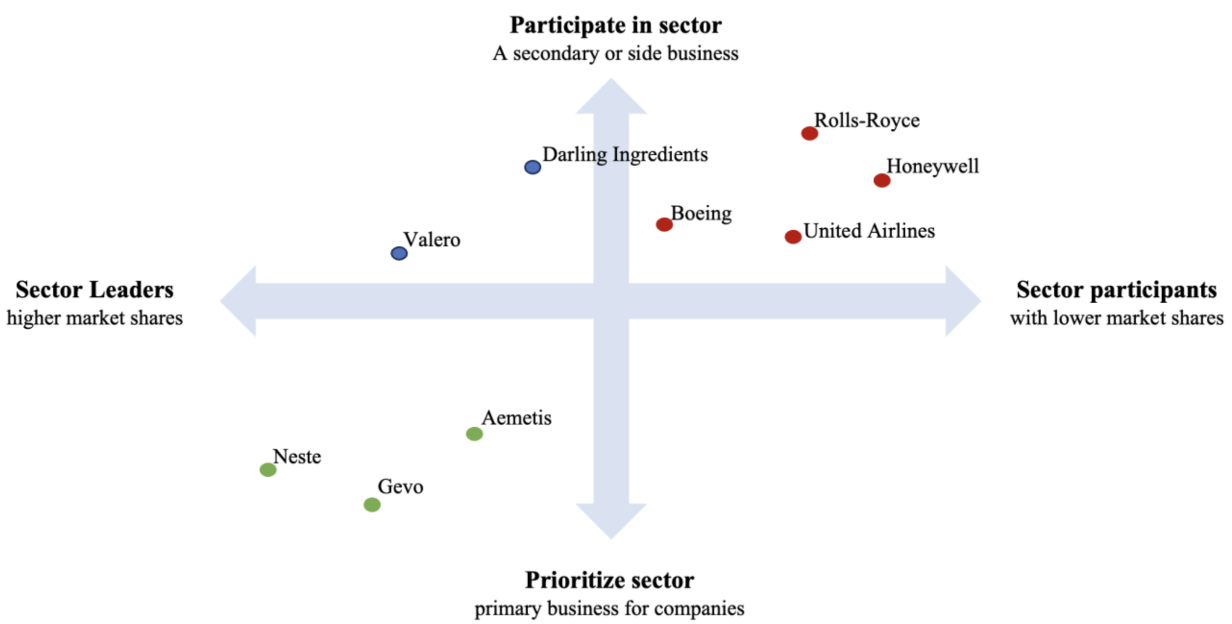
[229] Klöwer, Milan, et al. "Quantifying Aviation's Contribution to Global Warming," *Environmental Research*, 2021

[230] Matt Thurber, "Boeing Agrees to Further Sustainable Aviation Fuel Development: Ain," *Aviation International News*, 13 Nov. 2023, www.ainonline.com/aviation-news/air-transport/2023-11-13/boeing-agrees-further-saf-development. Accessed 14 Nov. 2023.

the global supply alone in 2022.[231] This makes it well-positioned to benefit from the additional tax credits immediately.

These examples contrast with the opportunities posed by some of the newly announced plants, in part because they are not expected to enter production until 2025 or 2026, when the IRA's tax credits will have expired. Although producers have been able to sell their initial production runs for the future, climate, and insurance-related risks unique to the Gulf Coast region mean that safer investments will be found with those organizations whose IRA-related windfalls are more immediate. While DG Fuel and Summit Agriculture are not publicly listed, investments based on these deals, such as the promise of profits from ***Honeywell's*** ethanol-to-jet process, should be regarded with a degree of caution. Thus, while Valero's and ***Darling's*** investment in SAF is a sign the industry has shifted, investors would do better to look up or downstream for new opportunities because this is where they may find more reward for relatively less risk. Thus, in addition to the manufacturers and carriers discussed throughout, investors may want to investigate important biofuel suppliers and producers, including ***Aemetis***, ***Gevo***, and ***Neste***, all of which turn biomass waste into renewable fuels and additives.

Figure 43. Matrix evaluation of key players for SAF production



Source: Columbia SIPA

[231] Saadi, Dania. "US-Based United Airlines Expects Inflation Reduction Act to Spur More SAF Output." S&P Global Commodity Insights, 29 Mar. 2023, www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/032923-us-based-united-airlines-expects-inflation-reduction-act-to-spur-more-saf-output#:~:text=That%20initiative%20aims%20to%20boost,year%20of%20SAF%20by%202050. Accessed 14 Nov. 2023.

PART 3
Conclusion

3.1 Conclusion

The IRA represents a milestone in the U.S. energy sector, aiming to address both climate change concerns and to stimulate domestic manufacturing. Through a multifaceted approach, the IRA seeks to invigorate the clean energy landscape within a range of up to sixteen sectors related to climate change mitigation. Among the IRAs many innovations are tax credit incentives for a range of activities that had not previously been supported by U.S. tax policy (e.g. clean hydrogen, utility-scale battery storage, clean commercial vehicles) combined with overlapping incentives for producers and purchases of targeted climate-mitigation equipment partially manufactured in the U.S. Specifically, the sections 45X PTCs and 48C ITC have amped up investment in clean energy manufacturing across the country. This has resulted in the establishment of new facilities, expansion of existing production capabilities, and increased employment. As the objective of this report was to identify investment opportunities enabled by the IRA, the investment activity already visible as a result of these incentives has been a particular focus with many leading players identified.

On top of the manufacturing sector, this report also identifies five other heretofore commercially challenged sectors that are showing signs of increased investment activity: Clean Hydrogen, Utility-Scale BESS, Clean Commercial Vehicles, Biofuels and SAF. This report analyzes these challenged sectors by examining recent project announcements and employing a structured framework to assess the suitability of publicly listed market participants for Citi Global Wealth clients seeking to engage in the evolving post-IRA landscape. This assessment, based on a two-factor sorting matrix – ranks players on one axis for their leadership in each sector (largely a comparison of each player's market share within each sector) and on the other axis ranks the priority each player places on the sector (an evaluation of the sector's importance to a company's overall business). The lower left quadrant of the sorting matrix identifies companies best-positioned in theory to benefit from the IRA's incentives within their respective sectors. Companies perceived as the sector leaders on the matrices are displayed in **Table 10**.

This report cannot constitute a definitive and exhaustive set of recommendations. Less than two years have gone by since the IRA was enacted; its effect on the market is only beginning to be observable. Nevertheless, this report can serve as a starting point for further analysis, tailored to the specific needs and preferences of individual clients. As the full impact of the IRA continues to unfold, the U.S. aims to increase its shares in global clean energy manufacturing along with expanding the other supported sectors will become more measurable. This report aims to provide an objective picture of this process, equipping investors with the necessary insights to navigate the evolving energy landscape.

Table 10. Summary table

Sector	Subsector	IRA provision	Key players
Domestic Manufacturing	Wind	45X, 48C	TPI Composites
			Vestas
	Solar	45X, 48C	Array Technologies
			Canada Solar
			First Solar
			NextTracker
	Battery components	30D, 45W, 45X, 48C	LG
			Panasonic Holdong Corp
			SK On Company Ltd.
	Mining/refining critical minerals	45X	Albermarle
			Compass Minerals
			IGO
			Lithium Americas
			Lundin Mining
			Rio Tinto
Clean Hydrogen	-	45V, 45Y, 48C	Bloom Energy
			Energy Volt
			Plug Power
Battery Energy Storage Systems	-	48A, 48E	Eos
			ESS
Commercial Clean Vehicles	-	30D, 45W	Ford
			Rivian
			Tesla
Biofuels	Ethanol	45X, 45Q, 48C	Adecoagro S.A
	Biodiesel		H.F. Sinclair
	Biogas		Kinder Morgan
	Ethanol/biodiesel/biogas		Valero Energy
Sustainable Aviation Fuels	-	40B	Aemetis
			Gevo
			Neste

Source: Columbia SIPA

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