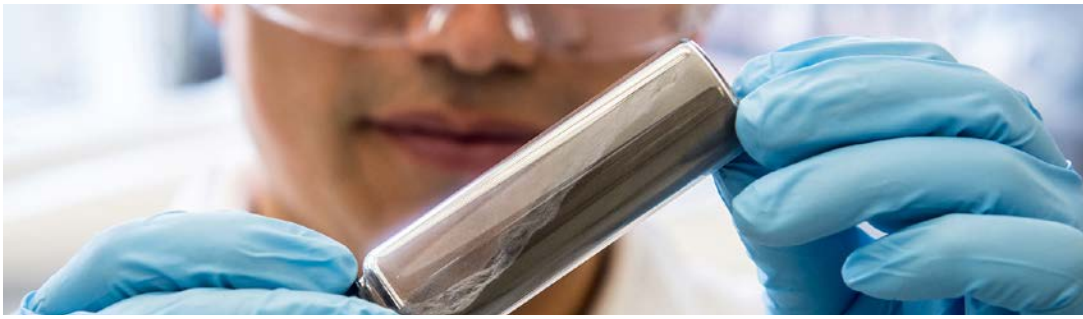
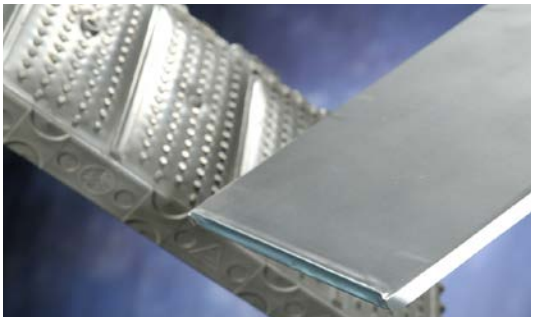
FCAB
FEDERAL CONSORTIUM FOR ADVANCED BATTERIES



EXECUTIVE SUMMARY

NATIONAL BLUEPRINT FOR LITHIUM BATTERIES 2021–2030



June 2021

A MESSAGE FROM THE SECRETARY

The Biden Administration has laid out a bold agenda to address the climate crisis and build a clean and equitable energy economy that achieves carbon-pollution-free electricity by 2035, and puts the United States on a path to achieve net-zero emissions, economy-wide, by no later than 2050[1] to the benefit of all Americans.

Jennifer M. Granholm
Secretary of Energy
U.S. Department of Energy

Lithium-based batteries power our daily lives from consumer electronics to national defense. They enable electrification of the transportation sector and provide stationary grid storage, critical to developing the clean-energy economy. The U.S. has a strong research community, a robust innovation infrastructure for technological advancement of batteries, and an emerging lithium-based, battery manufacturing industry.

Establishing a domestic supply chain for lithium-based batteries requires a national commitment to both solving breakthrough scientific challenges for new materials and developing a manufacturing base that meets the demands of the growing electric vehicle (EV) and stationary grid storage markets.

This National Blueprint for Lithium Batteries, developed by the Federal Consortium for Advanced Batteries will help guide investments to develop a domestic lithium-battery manufacturing value chain that creates equitable clean-energy manufacturing jobs in America while helping to mitigate climate change impacts.

Signed,

Jennifer M. Granholm
Secretary of Energy
U.S. Department of Energy

[1] Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," January 27, 2021.

OVERVIEW

This document outlines a national blueprint to guide investments in the urgent development of a domestic lithium-battery manufacturing value chain that creates equitable clean-energy manufacturing jobs in America, building a clean-energy economy and helping to mitigate climate change impacts. The worldwide lithium-battery market is expected to grow by a factor of 5 to 10 in the next decade.[2] The U.S. industrial base must be positioned to respond to this vast increase in market demand that otherwise will likely benefit well-resourced and supported competitors in Asia and Europe.

The Federal Consortium for Advanced Batteries (FCAB) is led by the Departments of Energy, Defense, Commerce, and State and includes many organizations across the government. FCAB brings together Federal agencies to provide a coordinated approach to ensuring a domestic supply of lithium batteries and accelerating the development of a robust and secure domestic industrial base. This blueprint details a path to achieving this desired outcome. Strong collaboration with U.S. academic institutions, national laboratories, industrial stakeholders, and international allies is an integral feature of this blueprint.

Vision for the Lithium-Battery Supply Chain

By 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements.

[2] Battery market projections provided in Figure 2.

VISION AND GOALS

Establishing a domestic supply chain for lithium-based batteries requires a national commitment to both solving breakthrough scientific challenges for new materials and developing a manufacturing base that meets the demands of the growing electric vehicle (EV) and electrical grid storage markets. As the domestic supply chain develops, efforts are needed to update environmental and labor standards and to ensure equitable development of workforce opportunities including those communities that have been historically underserved. Attainment of the following five goals will position the United States to secure this vision:

GOAL 1 Secure access to raw and refined materials and discover alternatives for critical minerals for commercial and defense applications

A robust, secure, domestic industrial base for lithium-based batteries requires access to a reliable supply of raw, refined, and processed material inputs along with parallel efforts to develop substitutes that are sustainable and diversify supply from both secondary and unconventional sources. The goal is to reduce U.S. lithium-battery manufacturing dependence on scarce materials, especially cobalt and nickel, in order to develop a stronger, more secure and resilient supply chain. Working through ongoing U.S. Government initiatives and with allies to secure reliable domestic and foreign sources for critical minerals[3] is as vital as ultimately replacing these materials in the lithium-battery supply chain. New or expanded production must be held to modern standards for environmental protection, best-practice labor conditions, and rigorous community consultation, including with tribal nations through government-to-government collaboration, while recognizing the economic costs of waste treatment and processing.

GOAL 2 Support the growth of a U.S. materials-processing base able to meet domestic battery manufacturing demand

Today, the U.S. relies on international markets for the processing of most lithium-battery raw materials. The Nation would benefit greatly from development and growth of cost-competitive domestic materials processing for lithium-battery materials. The elimination of critical minerals (such as cobalt and nickel) from lithium batteries, and new processes that decrease the cost of battery materials such as cathodes, anodes, and electrolytes, are key enablers of future growth in the materials-processing industry.

GOAL 3 Stimulate the U.S. electrode, cell, and pack manufacturing sectors

Significant advances in battery energy storage technologies have occurred in the last 10 years, leading to energy density increases and battery pack cost decreases of approximately 85%, reaching $143/kWh in 2020.[4] Despite these advances, domestic growth and onshoring of cell and pack manufacturing will require consistent incentives and support for the adoption of EVs. The U.S. should develop a federal policy framework that supports manufacturing electrodes, cells, and packs domestically and encourages demand growth for lithium-ion batteries. Special attention will be needed to ensure access to clean-energy jobs and a more equitable and durable supply chain that works for all Americans. In addition, electrode, cell, and pack manufacturing can benefit from further research and development (R&D) in order to reduce costs, improve performance, and support demand growth.

GOAL 4 Enable U.S. end-of-life reuse and critical materials recycling at scale and a full competitive value chain in the United States

Recycling of lithium-ion cells not only mitigates materials scarcity and enhances environmental sustainability, but also supports a more secure and resilient, domestic materials supply chain that is circular in nature. For lithium-ion batteries, several factors create challenges for recycling. Currently, recyclers face a net end-of-life cost when recycling EV batteries, with costs to transport batteries, which are currently classified as hazardous waste, constituting over half of the end-of-life recycling costs. New methods will be developed for successfully collecting, sorting, transporting, and processing recycled lithium-ion battery materials, with a focus on reducing costs. In addition to recycling, a resilient market should be developed for the reuse of battery cells from retired EVs for secondary applications, including grid storage. Second use of battery cells requires proper sorting, testing, and balancing of cell packs.

[3] The term 'critical material or mineral' means a material or mineral that serves an essential function in the manufacturing of a product and has a high risk of a supply disruption, such that a shortage of such a material or mineral would have significant consequences for U.S. economic or national security. Consolidated Appropriations Act, 2021. H.R. 133, 116th Cong. (2021). Page 1381. https://www.congress.gov/116/bills/hr133/BILLS-116hr133enr.pdf. Accessed May 27, 2021.

[4] U.S. Department of Energy, Energy Storage Grand Challenge Roadmap, 2020, Page 48. https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challenge%20Roadmap.pdf. Accessed May 27, 2021.

GOAL 5 Maintain and advance U.S. battery technology leadership by strongly supporting scientific R&D, STEM education, and workforce development

Establishing a competitive and equitable domestic lithium-battery supply chain in an accelerating EV and grid storage market is only one phase of a global surge toward higher performance and lower costs as part of a new zero-carbon energy economy. The pipeline of R&D, ranging from new electrode and electrolyte materials for next generation lithium-ion batteries, to advances in solid state batteries, and novel material, electrode, and cell manufacturing methods, remains integral to maintaining U.S. leadership. The R&D will be supported by strong intellectual property (IP) protection and rapid movement of innovations from lab to market through public-private R&D partnerships like those established in the semiconductor industry. Undertaking R&D requires a highly skilled workforce, which starts with equitable access to science, technology, engineering, and math (STEM) education at all levels.

OUR PATH FORWARD

Advanced batteries are increasingly important for multiple commercial markets, including electric vehicles, stationary storage systems, and aviation, as well as for national defense uses. This document outlines a U.S. national blueprint for lithium-based batteries, developed by FCAB to guide federal investments in the domestic lithium-battery manufacturing value chain that will decarbonize the transportation sector and bring clean-energy manufacturing jobs to America.

FCAB brings together federal agencies interested in ensuring a domestic supply of lithium batteries to accelerate the development of a resilient domestic industrial base FCAB is promoting a holistic approach covering the whole lithium-based battery ecosystem, focusing on development of an equitable, sustainable supply chain, from raw-materials production to end-of-life recycling. For each stage of the supply chain, this blueprint identifies key actions that federal agencies can take to strengthen and bolster domestic performance, while progressing towards national goals for mitigating climate change and advancing social justice.

Beyond the supply chain, FCAB is working to promote other factors necessary to develop a secure domestic battery ecosystem, including identifying influential federal policies and authorities, enhancing protection of IP and knowledge transfer, accelerating the development of lithium-based battery materials and technologies to maintain U.S. battery technology leadership, and bolstering technology transfer across commercial and defense markets.

To establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and job creation, enables decarbonization goals, and meets national security requirements, the FCAB will:

- □ **Secure U.S. access to raw materials for lithium batteries** by incentivizing growth in safe, equitable, and sustainable domestic mining ventures while leveraging partnerships with allies and partners to establish a diversified supply
- □ Establish a program to **increase domestic processing and production of critical battery materials** by expanding existing capacity and creating new capacity using existing technology; establish a Research, Development, Demonstration & Deployment (RDD&D) program to discover and produce alternatives for critical battery materials
- □ Implement policies and support that **enable the expansion of U.S. lithium-battery manufacturing**, including electrodes, cell, and pack production to ultimately meet the future needs of electric and grid storage production as well as security applications
- □ Establish and support U.S. industry to implement a blueprint that will **enable a secure domestic lithium-battery recycling ecosystem** to reduce constraints imposed by materials scarcity, enhance environmental sustainability, and support a U.S.-based circular materials supply chain
- □ Support **research**, **development**, and **demonstration** from academic institutions, national laboratories, and U.S.-based industries into all aspects of the lithium-battery supply chain for commercial and defense applications, thus enabling the development and commercialization of **revolutionary battery materials** and **battery technologies**
- □ Support development of a **trained battery supply chain workforce** that promotes career transition and equitable access through programs in trade schools, community colleges, and public universities
- □ Determine new approaches to create and implement **public-private partnerships** to encourage private investments and ensure alignment with the national blueprint

UNITED STATES NATIONAL BLUEPRINT FOR LITHIUM BATTERIES

This document outlines a U.S. lithium-based battery blueprint, developed by the Federal Consortium for Advanced Batteries (FCAB), to guide investments in the domestic lithium-battery manufacturing value chain that will bring equitable clean-energy manufacturing jobs to America.

FCAB brings together federal agencies interested in ensuring a domestic supply of lithium batteries. This blueprint delineates elements of the lithium-battery supply chain, current federal efforts in support of domestic manufacturing, as well as key actions that can be taken by U.S. agencies to increase domestic manufacturing capabilities. Through this blueprint, the federal agencies will support domestic supply of lithium batteries and accelerate the development of a robust, secure, and healthy domestic research and industrial base. Further, the blueprint will support a strong domestic ecosystem for future alternatives to lithium chemistries. Woven into the blueprint is the creation of a trained battery supply-chain workforce that promotes career transition and equal access through training and education programs in trade schools, community colleges, and public universities.

Vision for the Lithium-Battery Supply Chain
By 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements.

Goals to Achieve Our Vision

- **Goal 1:** Secure access to raw and refined materials and discover alternatives for critical minerals for commercial and defense applications
- **Goal 2:** Support the growth of a U.S. materials-processing base able to meet domestic battery manufacturing demand
- **Goal 3:** Stimulate the U.S. electrode, cell, and pack manufacturing sectors
- **Goal 4:** Enable U.S. end-of-life reuse and critical materials recycling at scale and a full competitive value chain in the U.S.
- **Goal 5:** Maintain and advance U.S. battery technology leadership by strongly supporting scientific R&D, STEM education, and workforce development

BACKGROUND

The Domestic and International Lithium-Battery Landscape

Lithium-ion batteries are pervasive in our society. Current and projected demand is dominated by electric vehicles (EVs), but lithium-ion batteries also are ubiquitous in consumer electronics, critical defense applications, and in stationary storage for the electric grid. With the increasing electrification of the U.S. transportation sector, growth in employment associated with EVs has already been demonstrated, with electric hybrids, plug-in hybrids, and all EVs supporting 198,000 U.S. employees in 2016,[5] and 242,700 U.S. employees by 2019.[6] Battery development and production are strategically important for the U.S., both as part of the transition to a clean-energy economy, and as a key element of the competitiveness of the automotive industry. In fact, automotive manufacturing drives $1.1 trillion into the economy each year through the sales and servicing of autos.[7] A 2017 estimate suggested that approximately 10 million U.S. jobs are directly associated with the automobile industry, and 5% of all U.S. jobs depend on the automotive sector.[8] Transportation accounts for about 28% of total U.S. greenhouse gas (GHG) emissions, making it the largest contributor to U.S. GHG emissions.[9] Decarbonizing the transportation sector through electrification will clean up our air, help address climate change, and build a clean-energy economy that benefits all communities in an equitable and just manner.

To retain a competitive manufacturing base, the U.S. needs a competitive EV industry supported by battery manufacturing. While estimates vary and projections can change dramatically, Bloomberg projects worldwide sales of 56 million passenger EVs in 2040, of which 17% (about 9.6 million EVs) will be in the U.S. market (FIGURE 1). If all batteries for Bloomberg's projected 9.6 million EVs were manufactured abroad, that would result in roughly $100 billion in imports.[10] Capturing this market is imperative for the future viability of the U.S. auto industry, which historically has contributed 5.5% of the total U.S. gross domestic product.[11] In addition to the EV market, grid storage uses of advanced batteries are also anticipated to grow, with Bloomberg projecting total global deployment to reach over 1,095 GW by 2040, growing substantially from 9 GW in 2018.[12] To participate in the lithium-based battery market, the U.S. needs a robust supply chain to produce state-of-the-art, reliable EV and grid storage batteries at scale.

Given the reliance on batteries, the electrified transportation and stationary grid storage sectors are dependent on critical materials; today's lithium-ion batteries include several critical materials, including lithium, cobalt, nickel, and graphite.[13] Strategic vulnerabilities in these sources are being recognized. In December 2017, the President signed Executive Order 13817 on *Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals* to reduce the nation's vulnerability to disruptions in the supply of critical minerals. This focus on critical minerals was further bolstered by Executive Order 13953 on *Addressing the Threat to the Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries*, signed in September 2020. New sources of critical materials must be identified to increase supply chain diversity, thereby reducing U.S. vulnerability to disruptions.

The challenge to creating a competitive and sustainable battery manufacturing industry in the United States is immense, and the country needs to move fast. Other countries have developed vertical battery manufacturing supply chains supported by their own national strategies, such as China's "*Made in China 2025*" strategy released in May 2015 and the European Union's "*Strategic Action Plan on Batteries*," released in May 2018. As China and

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[5] US Department of Energy, "2017 US Energy and Employment Report (USEER)," January 2017. https://www.energy.gov/sites/default/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf. Accessed November 9, 2019.

[6] US Department of Energy, "2019 US Energy and Employment Report (USEER)," January 2019. https://www.usenergyjobs.org/2019-report. Accessed March 31, 2021.

[7] Alliance for Automotive Innovation, "Driving the U.S. Economy," 2020. https://www.autosinnovate.org/initiatives/the-industry. Fueling the Economy fact. Accessed April 27, 2021.

[8] Alliance for Automotive Innovation, "Economic Insights," 2020. https://www.autosinnovate.org/resources/insights. Industry Impact fact. Accessed May 10, 2021.

[9] https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation#:~:text=%E2%80%8BGreenhouse%20gas%20(GHG)%20emissions,terms%20than%20any%20other%20sector. Accessed 04 March 2021.

[10] Assumes each EV will have a 100-kWh battery pack produced at $100/kWh, making the cost $10,000 per battery pack. The $100B market is based on $10,000 per pack and approximately 10M EVs sold in 2040.

[11] Alliance for Automotive Innovation, "Fueling the Economy fact," 2020. https://www.autosinnovate.org/initiatives/the-industry. Accessed April 27 2021.

[12] BloombergNEF, *Long-Term Energy Storage Outlook 2019*. https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/. Accessed 1 April 2021.

[13] Manganese is a material to watch given it is on the United States Geological Survey list and has the potential to increase in content in the cathode if the long-term goal is to reduce or eliminate Nickel (Ni) and Cobalt (Co) content.

others ramp up production capacity, they stand to gain a first-mover pricing advantage from economies of scale, process learning, and control of critical inputs, impacting the competitiveness of U.S. industry. The lithium-ion battery industry appears to be at a tipping point, with costs having decreased nearly 90% since 2010.[14] This technology is disrupting transportation markets worldwide and has the potential to reshape global industries in the decades to come. China is projected to have 1,811 GWh of lithium cell production capacity in 2025,[15] capable of supporting cost-competitive EV production up to the equivalent of one quarter of 2020 global passenger EV sales, as shown in FIGURE 1.

Projections of Future Market Growth

Currently, the U.S. market for lithium-ion batteries, or alternative rechargeable battery chemistries, can be delineated into the commercial and the national defense markets. While these markets are distinct in their end-use applications and requirements, they are alike in their need for innovation and R&D. Successful domestic production and reliable supply chains in both markets will be imperative for our country's economic competitiveness and security.

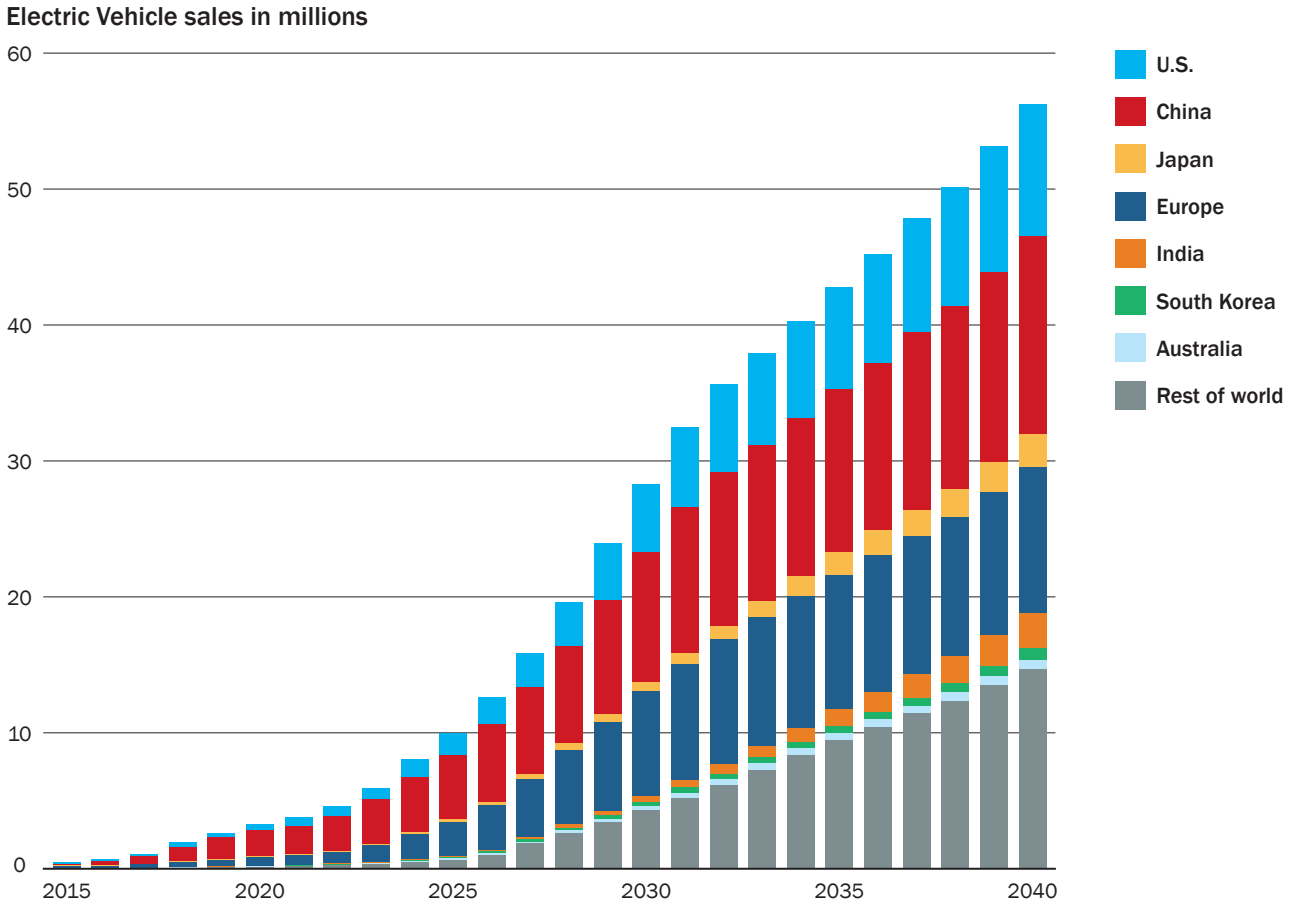

FIGURE 1. Annual Sales of Passenger EVs (Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs)). Source: BloombergNEF Long-Term Electric Vehicle Outlook 2019.[16]

[14] BloombergNEF, "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh", December 16, 2020. https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/. Accessed May 27, 2021.

[15] "Lithium-Ion Battery Megafactory Assessment", Benchmark Mineral Intelligence, March 2021. Used with Permission from Benchmark. https://www.benchmarkminerals.com/megafactories/.

[16] Bloomberg New Energy Finance Long-Term Electric Vehicle Outlook 2019. Page 2 of Executive Summary. https://bnef.turtl.co/story/evo-2020/page/3?teaser=yes. Accessed May 27, 2021.

Commercial Markets

For lithium-ion batteries, commercial U.S. markets include commercial and passenger EVs, stationary storage, and aviation. As seen in FIGURE 2, lithium-ion EV battery demand is projected to grow dramatically in the coming years.

ELECTRIC VEHICLES MARKET

For EVs, the leading battery technology is expected to be lithium-based, which offer high energy, high power, and long lifetimes compared to other currently available battery systems. EVs are a critical driver of the demand for lithium-ion batteries and are the primary market focus when outlining the need for domestic lithium-ion battery manufacturing.

While U.S.-based manufacturing of lithium-ion batteries needs to greatly expand to meet the needs of the growing domestic market, the country has a strong foundation on which to build additional manufacturing capacity. Of the 747 GWh of global EV lithium-ion cell manufacturing in 2020 (FIGURE 3), the U.S. capacity is approximately 8% (about 59 GWh).[17] Global cell manufacturing for EVs is anticipated to grow to 2,492 GWh by 2025 with U.S. capacity expected to grow to 224 GWh. However, demand from U.S. annual sales of passenger EVs alone is projected to surpass this anticipated 224 GWh of lithium-ion cell manufacturing capability in 2025.[18]

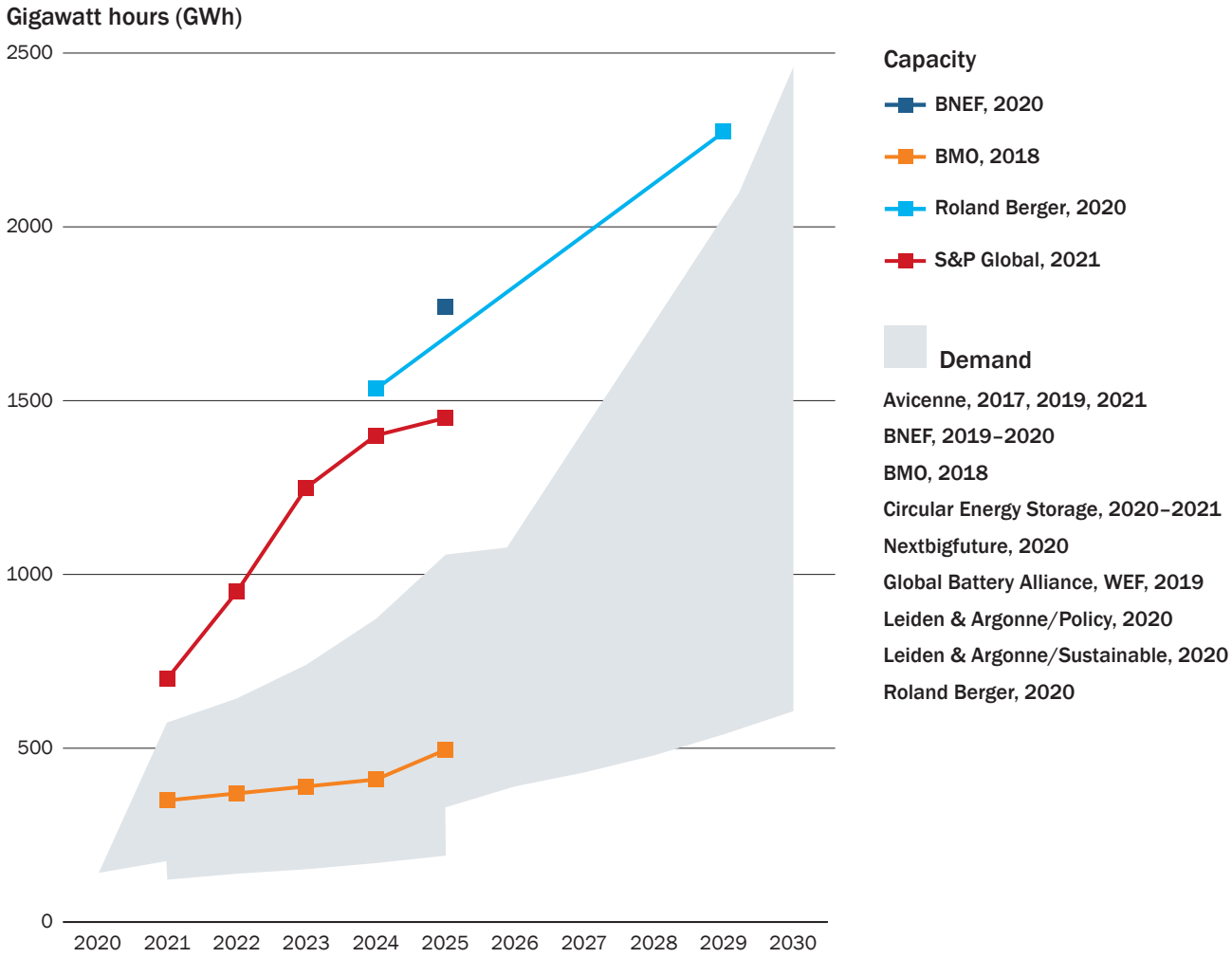

FIGURE 2. Global Lithium-ion EV Battery Demand Projections. Source: Argonne National Laboratory ANL/ESD-21/3.[19]

[17] "Lithium-Ion Battery Megafactory Assessment", Benchmark Mineral Intelligence, March 2021. Available for purchase. https://www.benchmarkminerals.com/megafactories/.

[18] "Lithium-Ion Battery Megafactory Assessment", Benchmark Mineral Intelligence, March 2021. Available for purchase. https://www.benchmarkminerals.com/megafactories/.

[19] Zhou Y, Gohlke D, Rush L, Kelly J, Dai Q. Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010–2020. *Argonne National Laboratory*. 2021; ANL/ESD-21/3. Page xv. https://publications.anl.gov/anlpubs/2021/04/167369.pdf. Accessed May 27, 2021.

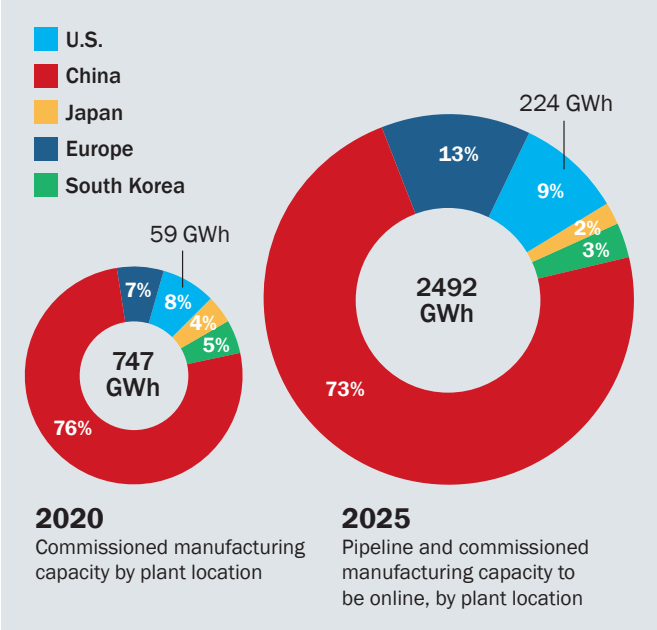

FIGURE 3. Cell manufacturing capacities.
Source: "Lithium-Ion Battery Megafactory Assessment", Benchmark Mineral Intelligence, March 2021.

STATIONARY STORAGE MARKET

With greater duration requirements and less stringent density and weight constraints, non-lithium storage technologies may emerge as the most cost-effective long-term solutions for stationary storage. However, through the first half of 2020, lithium-ion batteries accounted for 98% of commissioned utility-scale stationary storage projects.[20] Stationary energy storage can benefit the electricity grid by providing many services such as enabling high penetration of intermittent renewable energy sources, serving remote communities, supporting transportation electrification, increasing resilience, optimizing energy production and usage, and supporting critical services like healthcare. Annual deployments of lithium-battery-based stationary energy storage are expected to grow from 1.5 GW in 2020 to 7.8 GW in 2025,[21] and potentially 8.5 GW in 2030.[22,23]

AVIATION MARKET

As with EVs, electric aircraft have the potential for emission-free air travel. A near-term developing market is electric vertical takeoff and landing (eVTOL) aircraft used for urban package delivery and air mobility for up to four passengers. The global eVTOL aircraft market is estimated to be between $162 million and $1 billion by 2025.[24, 25] The next aviation market segment is expected to be the all-electric or hybrid-electric commuter aircraft with about ten passengers. There are strong global growth opportunities for the hybrid electric regional aircraft market following the introduction of the first 50- to 70-seat hybrid electric aircraft which is planned for 2028.[26] Advanced lithium-ion batteries with high specific energy and power density have the potential to enable electric aircraft propulsion. Current and developmental lithium-ion batteries could enable the initial commercial introduction of eVTOL aircraft; however, significant advances in lithium-ion battery technologies will be required for expansion of the commercial electric aircraft market to multiple classes of aircraft such as large regional and single-aisle 737-class aircraft. Aviation applications have the potential to be an early adopter of next-generation high specific energy battery technologies, which may not yet meet the calendar life and durability requirements for automotive applications. Such early adoption of advanced battery technologies in the electric aviation market offers the potential for accelerating commercialization of next-generation battery technologies.

[20] Longson, Michael. Storage Company and Project Database: First quarter 2021. May 2021. No URL. PowerPoint Presentation.
[21] Wood Mackenzie Power & Renewables/U.S. Energy Storage Association. U.S. Energy Storage Monitor, 2020 Year in Review Full Report. March 2021.
[22] Abhyankar, N. et. al. 2030 Report: Powering America's Clean Economy. April 2021. Accessed April 27, 2021. Source: https://energyinnovation.org/publication/2030-report-powering-americas-clean-economy/.
[23] Larson, et. al. Net-Zero America: Potential Pathways, Infrastructure, and Impacts. December 15, 2020. Source: https://netzeroamerica.princeton.edu/img/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf. Accessed April 27, 2021.
[24] https://www.marketsandmarkets.com/Market-Reports/evtol-aircraft-market-28054110.html?gclid=Cj0KCQiAyJOBBhDCARIsAJG2h5cDgh3GLJsZQLCTNxUdSA_o0IRX0wFyLXM8KUlon0OKzKi5FFLtQ6QaAo51EALw_wcB. Accessed 11 February 2021.
[25] https://www.marketresearchfuture.com/reports/evtol-aircraft-market-7952. Accessed 11 February 2021.
[26] Perry, Dominic. "UK Firm EAG Details Development Roadmap for Hybrid-Electric Regional Airliner." *Flight Global*, Flight Global, 7 Aug. 2020, www.flightglobal.com/air-transport/uk-firm-eag-details-development-roadmap-for-hybrid-electric-regional-airliner/139641.article. Accessed May 26, 2021.

National Defense Markets

In addition to the economic imperative for a competitive EV and advanced battery sector, the Defense Department (DoD) requires reliable, secure, and advanced energy storage technologies to support critical missions carried out by joint forces, contingency bases, and at military installations. Faced with increasing kinetic and non-kinetic threats, the Department is shifting toward more distributed, austere, and autonomous operational concepts carried out by platforms and installations with escalating power requirements. As such, DoD prefers domestically sourced, high-density energy storage to support agile forces utilizing power-hungry propulsion, communications, sensors, and weapons. However, the DoD supply chain is challenged due to the unique nature of batteries for weapons systems, as well as constituting only a small percentage of the larger commercial market for advanced batteries. As advanced lithium-ion batteries become strategically important, so too do assured sources of critical minerals and materials needed to sustain a robust and resilient domestic industrial base.

The military requires thousands of unique types of batteries each year resulting in over $200 million in annual procurements from the Defense Logistics Agency (DLA). In addition, this data accounts for only a portion of overall annual demand from across DoD, which includes numerous program-specific procurements across each of the services.

Advanced batteries for these combat applications have a series of requirements that distinguish defense applications from the larger commercial marketplace. Foremost, military platforms, sensors, weapons, and individual warfighters operate in conditions not typically present in the commercial market. The military uses batteries in systems that operate at extreme cold or hot temperatures, encounter high shock and vibration, and that may be stored for long periods before being required to be ready for immediate use in a short time. Defense battery systems are at times operated in environments where safety demands exceed commercial requirements and are subject to a range of kinetic and cyber threats. While lacking a formal estimate, DoD believes demand for these batteries will grow, not just from traditional uses such as combat platforms, weapons, sensors and individual warfighter equipment, but also from the hybridization of the combat platforms and introduction of tactical microgrids.

U.S. Economic Posture

Bloomberg forecasts 3.2 million EV sales in the U.S. for 2028,[27] and over 200 GW of lithium-ion battery-based grid storage deployed globally by 2028.[28] With an average EV battery capacity of 100 kWh, 320 GWh of domestic lithium-ion battery production capacity will be needed just to meet passenger EV demand. Benchmark Mineral Intelligence forecasts U.S. lithium-ion battery production capacity of 148 GWh by 2028,[29] less than 50% of projected demand. These projections show there is a real threat that U.S. companies will not be able to benefit from domestic and global market growth, potentially impacting their long-term financial viability. Our supply chains for the transportation, utility, and aviation sectors will be vulnerable and beholden to others for key technologies necessary for advancement. Without action, the U.S. risks long-term dependence on foreign sources of batteries and critical materials.

National Security Posture

Maintaining and expanding lithium cell and battery manufacturing capability here in the U.S.—as well as in allied and partner countries—is critical to U.S. national security and is essential to developing resilient defense supply chains not under threat from near-peer adversaries.[30] While the supply chain security of minerals, materials, and cells is of concern today, within the military the rising demand and diversity of applications for lithium battery technologies make future strategic concerns even more dire. To meet surface, undersea, space, air, and ground operational requirements, the military will need reliable and secure advanced storage technologies. The DoD is presently unable to leverage much of the large commercial investment in battery technology for state-of-the-art capability, nor can DoD field battery-enabled weapons and platforms free of adversary supply chain control. Addressing these concerns requires the defense community to leverage other federal agencies and international partners in support of a secure battery supply chain for the advanced batteries it needs.

Global Competition and Industrial Policies

China is the largest global EV market and dominates the supply chain for the manufacture of lithium-ion batteries, including the processing of minerals and raw materials. China relies on massive incentives to support domestic EV manufacturing, retail-level subsidies to create demand for domestic products, and a battery certification program to limit market access for foreign products.

Europe and India are developing policy initiatives (mainly mandates and incentives) and programs to counter China's dominance in lithium-ion battery production and localize supply chains within their own regions. The European Union has prioritized batteries under the European Commission's industrial policy through the European Battery Alliance, which launched in 2017 and developed a strategic plan to secure battery manufacturing and access to critical materials across the entire supply chain.

Japanese and Korean manufacturers are involved in most cell production investments outside of the Chinese market. Both have substantial investments in the Chinese and U.S. markets; but their domestic EV markets are not driving substantial growth, so most of their new cell production investments are occurring in the larger Chinese, European, and North American markets.

[27] BloombergNEF, *Long-Term Electric Vehicle Outlook 2019*. Page 2. https://bnef.turtl.co/story/evo-2020/page/3?teaser=yes. Accessed May 27, 2021.
[28] BloombergNEF, *Long-Term Energy Storage Outlook 2019*. Page 10 of Executive Summary. https://about.bnef.com/new-energy-outlook/. Accessed May 27, 2021.
[29] https://www.visualcapitalist.com/battery-megafactory-forecast-1-twh-capacity-2028/. Accessed 01 April 2021.
[30] *Offshore Battery Production Poses Problems for Military*. National Defense Magazine (18 November 2018).

ASSESSMENT OF THE U.S. BATTERY MANUFACTURING INDUSTRY

Relative to its foreign counterparts, the U.S. typically encourages private-sector, market-driven approaches to industrial development. There are various federal and state policies that impact the development of battery storage systems, but these are generally not coordinated across levels of government.

Longstanding strengths, such as the R&D capabilities embodied in U.S. companies, universities, and national laboratories, may be undercut by weak IP protection and technology transfer policies. The administration's support for deep decarbonization of the U.S. economy and the refreshed trade structure of the United States-Mexico-Canada Agreement (USMCA) offer opportunities to improve the U.S. competitive position, but the U.S. must gain on China, which continues to rapidly expand capacity.

An evaluation of the U.S. position in global battery manufacturing is shown in the graphic (FIGURE 4) below.

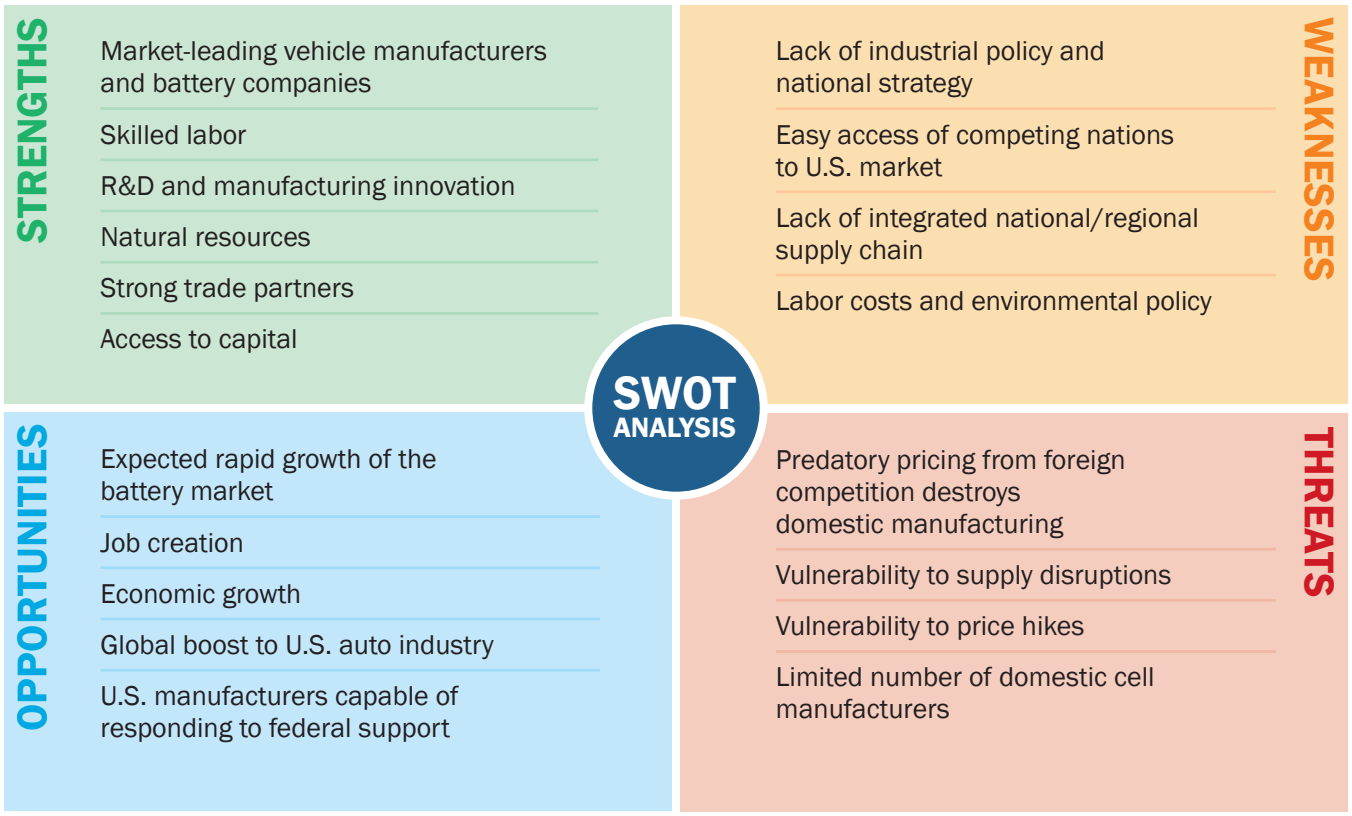

FIGURE 4. Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis of the U.S. position in global battery manufacturing.

NATIONAL LITHIUM BATTERIES BLUEPRINT

The FCAB blueprint is a **holistic approach that** covers the **whole** lithium-ion battery ecosystem, and focuses on development of a **sustainable**, **domestic supply chain**.

FIGURE 5 outlines the current lithium-battery supply chain, from raw materials production to end-of-life recycling. For each stage of the supply chain, FCAB proposes key actions that can be taken to strengthen and bolster domestic performance while providing equitable clean-energy manufacturing jobs.

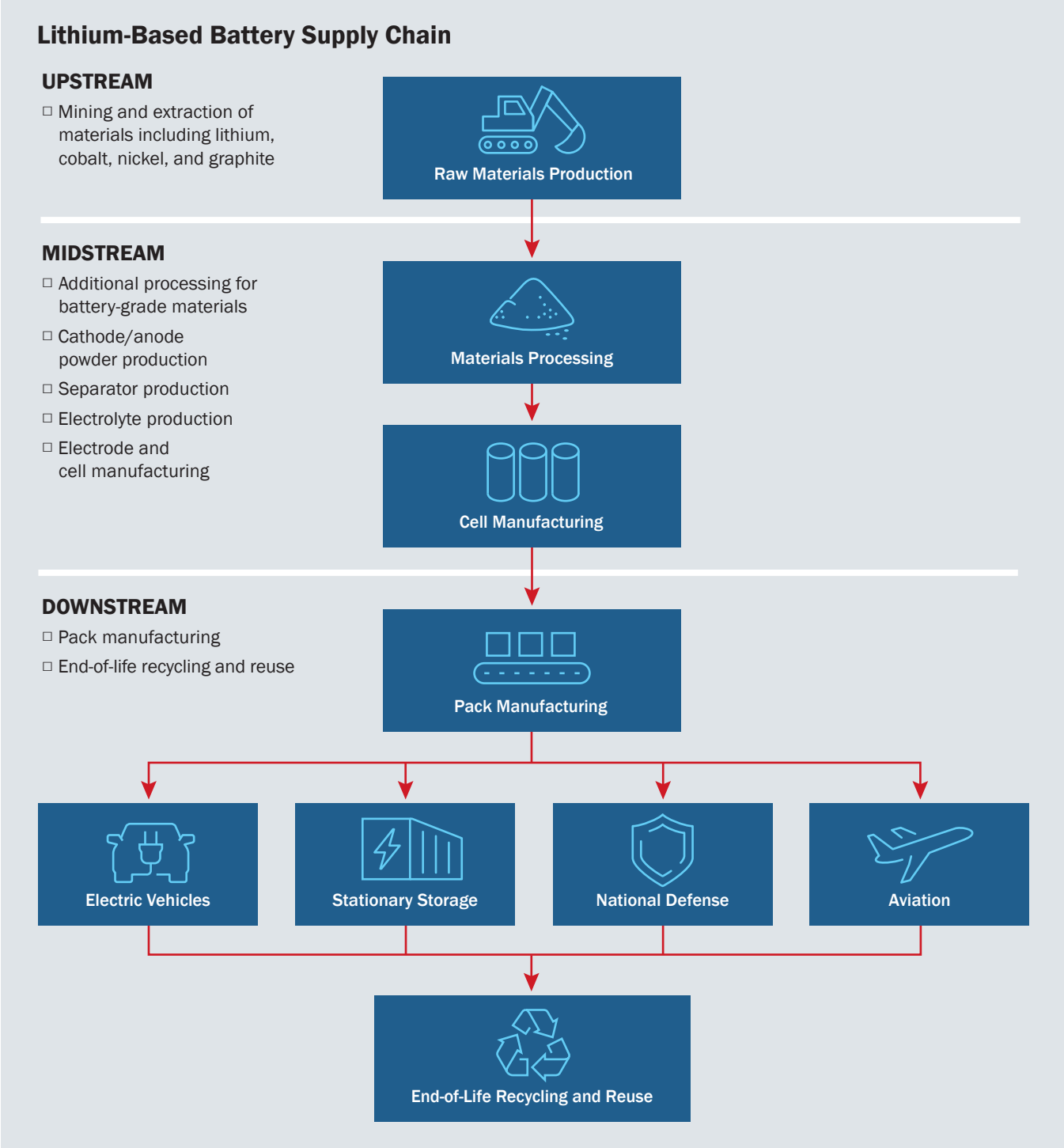

FIGURE 5. Steps in the lithium-battery material supply chain.

GOAL 1 Secure access to raw and refined materials and discover alternatives for critical minerals for commercial and defense applications

A robust, secure, domestic industrial base for lithium-based batteries requires access to a reliable supply of raw, refined, and processed material inputs for lithium batteries. The goal is to reduce U.S. battery manufacturing dependence on scarce materials, or those controlled by unreliable partners, in order to develop a stronger and more secure supply chain.

New mineral extraction must be held to modern environmental standards, require best-practice labor conditions, and conduct rigorous community consultation, including with tribal nations through government-to-government collaboration, while recognizing the economic costs of waste treatment and processing.

NEAR-TERM OBJECTIVES (2025)

1. Work with partners and allies to establish reliable sources and supplies of key raw materials for batteries, including critical minerals, both domestic and international
2. Increase U.S. safe and sustainable production capacity of critical battery minerals (lithium, nickel, and cobalt) by supporting R&D and mining efforts
3. Develop federal policies to support the establishment of resilient domestic and global sources and supplies of key raw materials

LONG-TERM OBJECTIVES (2030)

1. Eliminate cobalt and nickel in lithium-ion batteries by supporting processing R&D efforts
2. Integrate recycled materials as a key component of a circular battery economy as committed to in Goal 5

TABLE 1. Comparison of U.S. mineral reserves and manufacturing capacities verses the world.

Element	U.S. Reserves (1000 Metric tons)	World Reserves (1000 Metric tons)	Total Manufacturing Capacity with U.S. reserves (GWh)	Total Manufacturing Capacity with world reserves (GWh)
Lithium	750	21,000	7470	209,163
Cobalt	53	7100	703	94,164
Nickel	100	94,000	167	156,510
Manganese	230,000	1,300,000	3,271,693	18,492,176

Source: Argonne National Laboratory derived from USGS mineral commodities summaries (2021) and simulations using BatPaC 4.0 for Li-ion batteries with $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$ cathode.

GOAL 2 Support the growth of a U.S. materials-processing base able to meet domestic battery manufacturing demand

Today, the U.S. relies on international markets for processing of most lithium-battery raw materials. The Nation could benefit greatly from development and growth of cost-competitive domestic materials processing for lithium-battery materials.

The following actions are vital to further enable the development of domestic, commercialized materials processing:

NEAR-TERM OBJECTIVES (2025)

1. Create incentives for the growth of domestic battery materials processing
2. Support the development of materials processing innovations to produce low/no cobalt active materials and enable scale up
3. Develop improved processes for existing materials to decrease cost and improve performance that enables a $60/kWh cell cost
4. Work with partners and allies to support supply chain diversification of processed materials.

LONG-TERM OBJECTIVES (2030)

1. Support the development of materials processing innovations to produce cobalt- and nickel-free active materials and enable scale up

TABLE 2. Midstream Lithium-ion Battery Manufacturing: Percentage of Total Manufacturing Capacity by Country for Various Battery Components.

Country	Cathodes Manufacturing (3 M tons)	Anode Manufacturing (1.2 M tons)	Electrolyte Solution Manufacturing (339,000 tons)	Separator Manufacturing (1,987 M sq. m)
United States	—	10%	2%	6%
China	42%	65%	65%	43%
Japan	33%	19%	12%	21%
Korea	15%	6%	4%	28%
Rest of World	10%	—	17%	2%

Source: BloombergNEF, Battery Components Manufacturing Asset Map 2019, Accessed March 15, 2021.

GOAL 3 Stimulate the U.S. electrode, cell, and pack manufacturing sectors

Significant advances in battery energy storage technologies have occurred in the last 10 years, leading to energy density increases and battery pack cost decreases of approximately 85%, reaching $143/kWh in 2020.[31] Despite these advances, current electrode, cell, and pack manufacturing approaches can and will always benefit from further R&D advances that reduce costs, improve performance and support demand growth. Domestic growth and onshoring of pack manufacturing will require consistent federal incentives, and support for the adoption of EVs. Special attention will be needed to ensure access to clean-energy jobs and a more equitable and durable supply chain that works for all Americans.

NEAR-TERM OBJECTIVES (2025)

1. Promote the development of novel cell designs that reduce processing time, enable faster cell assembly, and decrease formation costs
2. Dedicate resources to expedite the scale-up and commercialization of novel technologies and manufacturing techniques
3. Develop form-fit-function battery standards for defense, EV, and grid applications
4. Develop a federal policy framework for supporting U.S. companies manufacturing of electrodes, cells, and packs domestically and that encourage demand growth for lithium-ion batteries

LONG-TERM OBJECTIVES (2030)

1. Meet critical defense battery demand with multiple-source domestic suppliers
2. Reduce the cost of EV pack manufacturing by 50% through development and validation of next-generation pack materials, component, and design innovations, and advanced manufacturing and assembly techniques

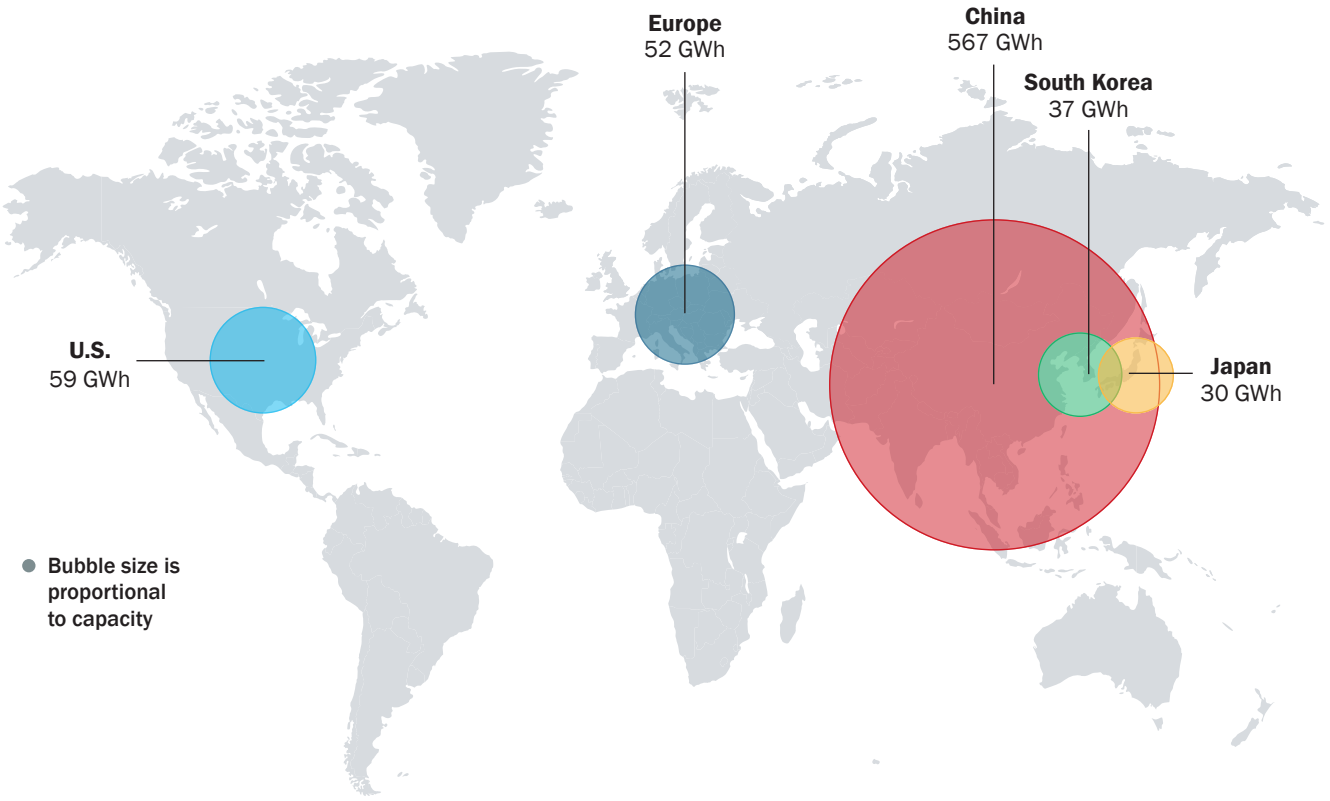

FIGURE 6. Cell manufacturing capacity by country or region.
Source: "Lithium-Ion Battery Megafactory Assessment", Benchmark Mineral Intelligence, March 2021.[32]

[31] U.S. Department of Energy, Energy Storage Grand Challenge Roadmap, 2020, Page 48. https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challenge%20Roadmap.pdf. Accessed May 27, 2021.
[32] https://www.benchmarkminerals.com/megafactories/. Accessed May 27, 2021.

GOAL 4 Enable U.S. end-of-life reuse and critical materials recycling at scale and a full competitive value chain in the U.S.

Recycling of lithium-ion cells not only reduces constraints imposed by materials scarcity and enhances environmental sustainability, but also supports a more secure and resilient domestic supply chain that is circular in nature (FIGURE 7). For lithium-ion batteries, several factors create challenges for recycling. Currently, there is an end-of-life net cost to recycling EV batteries, with costs to transport batteries, currently classified as hazardous waste, to recyclers accounting for over half of the end-of-life recycling costs. Beyond the recycling supply, spent EV battery cells can be transitioned to second-use applications, including grid storage. Second use of battery cells will require better methods for sorting, testing, and balancing of cell packs.

The following actions will increase recycling penetration into the commercial market for lithium-ion batteries, helping to create a domestic circular battery economy:

NEAR-TERM OBJECTIVES (2025)

1. Foster the design of battery packs for ease of second use and recycling
2. Establish successful methods for collecting, sorting, transporting, and processing recycled lithium-ion battery materials, with a focus on reducing costs
3. Increase recovery rates of key materials such as cobalt, lithium, nickel, and graphite
4. Develop processing technologies to reintroduce these materials into the supply chain
5. Develop methodologies for proper sorting, testing, and balancing for second use applications
6. Establish federal recycling policies to promote collection, reuse, and recycling of lithium-ion batteries

LONG-TERM OBJECTIVES (2030)

1. Create incentives for achieving 90% recycling of consumer electronics, EV, and grid-storage batteries
2. Develop federal policy requiring the use of recycled materials in cell manufacturing materials streams

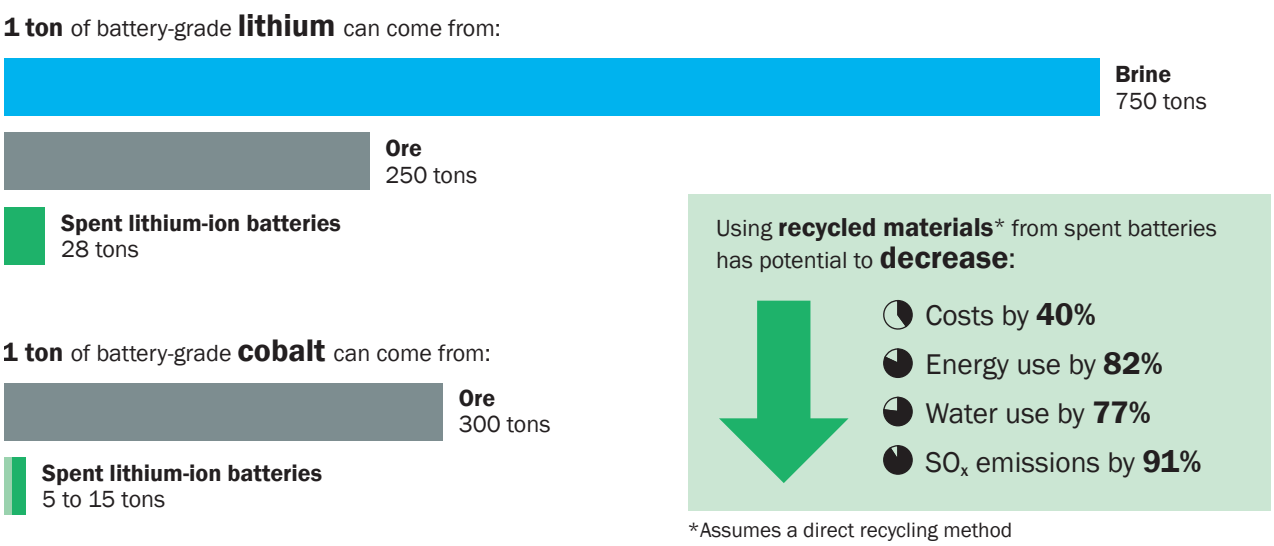

FIGURE 7. Benefits of recycling for lithium-ion batteries. Data from Argonne National Laboratory's ReCell Center, 2019.[33]

[33] Gaines L, Dai Q, Vaughey JT, Gillard S. Direct Recycling R&D at the ReCell Center. *Recycling*. 2021; 6(2):31. https://doi.org/10.3390/recycling6020031. Accessed May 27, 2021.

GOAL 5 Maintain and advance U.S. battery technology leadership by strongly supporting scientific R&D, STEM education, and workforce development

Establishing a competitive and equitable domestic lithium-battery supply chain in an accelerating EV and grid storage market is only the initial phase in a global surge to higher performance and lower costs with reductions in climate impact. The pipeline of R&D, ranging from new electrode and electrolyte materials for next-generation lithium-ion batteries, to advances in solid-state batteries, and novel material, electrode, and cell manufacturing methods remains integral to maintaining U.S. leadership. The R&D will be supported by strong IP protection and rapid movement of innovations from lab to market through public-private R&D partnerships such as those established in the semiconductor industry.

NEAR-TERM OBJECTIVES (2025)

1. Support research to develop cobalt-free cathode materials and electrode compositions focused on important metrics such as energy density, electrochemical stability, safety, and cost that outperform their current commercial, imported counterparts
2. Develop partnerships for technology transfer and standardization of pre-application testing protocols to ensure battery technology invented in the U.S. stays in the U.S.
3. Launch government-wide standardization of lithium-based battery technologies and configurations, enhancing the ability of niche government markets such as defense to rapidly transition lithium-based battery technology to their programs and benefit from a robust, equitable, sustainable domestic supply chain
4. Develop a plan for enhancement of IP protection strategies, research security, domestic manufacturing export-control policies, and for engagement of international allies
5. Work with industry partners to identify workforce needs and support educational programming

LONG-TERM OBJECTIVES (2030)

1. Develop cobalt- and nickel-free cathode materials and electrode compositions that improve important metrics such as energy density, electrochemical stability, safety, and cost and outperform their current commercial, imported counterparts
2. Accelerate R&D to enable the demonstration and at-scale production of revolutionary battery technologies including solid-state and Li-metal, that achieve a production cost of less than $60/kWh, a specific energy of 500 Wh/kg, and are cobalt- and nickel-free.

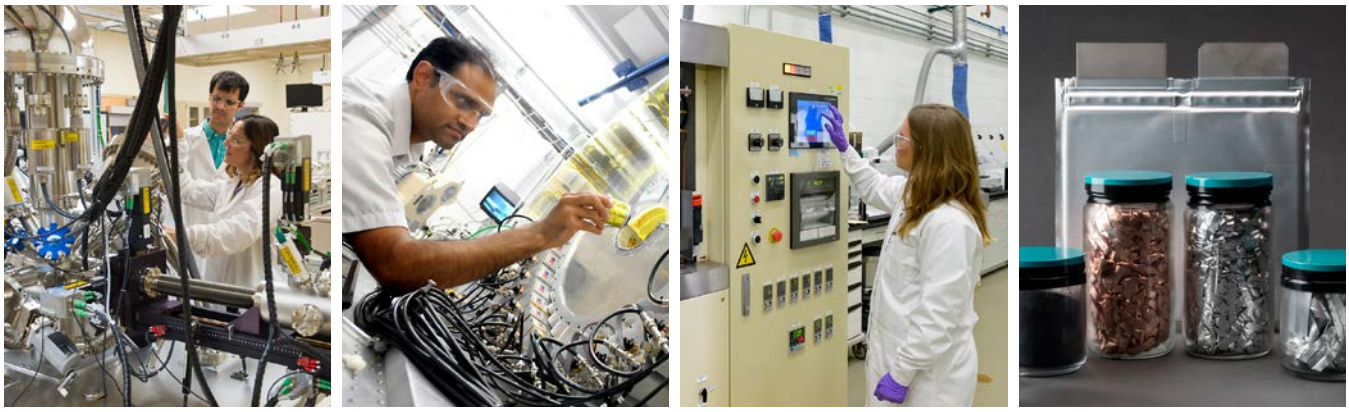

FIGURE 8. The U.S. has a strong R&D pipeline encompassing discovery of new materials, material and device manufacturing, performance characterization, and recycling. Source: Images courtesy of Argonne National Laboratory, April 2021.

These goals, taken together, serve as a holistic blueprint to maintain and expand U.S. leadership in R&D and manufacturing of lithium batteries across the supply chain. Woven into the goals is the creation of a trained battery-supply-chain workforce that promotes career transition and equal access through programs in trade schools, community colleges, and public universities.

SUMMARY

Lithium-based battery storage systems are becoming increasingly important for commercial markets, including electric vehicles, stationary grid-storage systems, and aviation, as well as national defense markets. The worldwide battery market is expected to grow by a factor of 5 to 10 over the next decade and there is a race to capture the market. Strengthening and bolstering U.S. competitiveness in advanced battery innovation and manufacturing is vital. The National Blueprint for Lithium Batteries laid out in this document provides a holistic approach to accelerate the development of a robust, secure, and healthy domestic research and industrial base for lithium-based batteries. The National Blueprint for Lithium Batteries will guide investments across the domestic battery manufacturing value chain that will decarbonize the transportation sector and bring equitable clean-energy manufacturing jobs to America.

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