Li-BRIDGE

Building a Robust and Resilient U.S. Lithium Battery Supply Chain

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Authors

Aakash Arora, *Boston Consulting Group*
Dr. William Acker, *New York Battery and Energy Storage Technology Consortium*
Brian Collie, *Boston Consulting Group*
Danny Kennedy, *New Energy Nexus*
David Roberts, *NAATBatt International/Indiana EDC*
Ian Roddy, *Boston Consulting Group*
James Greenberger, *NAATBatt International*
John Cerveny, *New York Battery and Energy Storage Technology Consortium*
Dr. Nathan Niese, *Boston Consulting Group*
Dr. Venkat Srinivasan, *Argonne National Laboratory*
Vijay Dhar, *New Energy Nexus*

Committees

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Brian Engle, *Amphenol*
Chris Larson, *Lithium Americas*
David Gelinas, *Lilac Solutions*
Denise Gray, *LG Energy Solution*
Dirk Spiers, *Spiers New Technologies*
Don Holmstrom, *Chemical Safety Board*
Edwin Shadeo, *Teck Resources*
Emily Smith, *American Electric Power*
Dr. Eric Dufek, *Idaho National Laboratory*
Dr. Eric Gratz, *Ascend Elements*
Dr. Esther Takeuchi, *Brookhaven National Laboratory*
Dr. Ilias Belharouak, *Oak Ridge National Laboratory*
Jeff Collins, *NextEra*
Jeff Dormo, *Honeywell*
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Dr. Job Rijssenbeek, *Albemarle*
Jonathan Weisgall, *Berkshire Hathaway Energy*
Julie Blunden, *New Energy Nexus*
Dr. Jun Liu, *Pacific Northwest National Laboratory*
Kunal Phalpher, *Li-Cycle*
Kurt Kelty, *Sila Nano*
Landon Mossburg, *Einride/Northvolt*
Lindsay Battenberg, *Proterra*
Mark Caffarey, *Umicore*
Dr. Mark Willey, *Pacific Northwest National Laboratory*
Dr. Noël Bakhtian, *Lawrence Berkeley National Laboratory*
Pierre Guyot, *John Deere*
Rohit Makharia, *SES*
Dr. Sanjiv Malhotra, *SparkZ*
Selin Tur, *CNH Industrial*
Seo Seung-il, *SK On*
Dr. Stan Whittingham, *SUNY Binghamton*
Dr. Sue Babinec, *Argonne National Laboratory*
Ted Miller, *Ford*
Dr. Tony Burrell, *National Renewable Energy Laboratory*
Dr. Willy Shih, *Harvard University*

Additional contributors to this report include:
Eva Almiñana, JT Clark, Rod Colwell, Dr. Michael Glotter, Jim Guiheen, Ziyan Sears, Vivan Song, and Dr. Richard Wang

Key Takeaways

In early 2022, the U.S. Department of Energy identified and brought together the leading experts in lithium battery technology from across the U.S. industry in a project called Li-Bridge. The purpose of Li-Bridge is to develop a strategy for establishing a robust and sustainable supply chain for lithium battery technology in North America.

Following ten months of consultation and study, Li-Bridge calls attention to the following facts:

- Lithium-based energy storage will be one of the key technologies of the 21st century. Lithium batteries will power the majority of vehicles manufactured over the next 50 years and will be essential to military systems, power grids (which are increasingly reliant on variable, renewable energy), and all manner of consumer, medical, and industrial electronics.
- Certain economic competitors of the United States recognized the importance of lithium battery technology nearly 20 years ago. Those competitors have invested heavily in it ever since. Although U.S. scientists originally invented lithium battery technology, the United States and U.S. companies today find themselves at least a decade behind in this critically important industrial sector. Key deficiencies are in manufacturing know-how and access to both raw and refined energy materials.
- U.S. companies today play only a minor role in the domestic and international markets for lithium battery production. The market for lithium battery cells in the U.S. is growing rapidly and expected to reach $55 billion per year by 2030.[1] Yet it is estimated that under current conditions U.S. companies and U.S. workers will capture less than 30% of the value of cells consumed domestically.
- The lack of a substantial lithium battery supply chain in the United States and the lack of secure access to energy materials pose serious threats to U.S. national and economic security. These threats will not only inhibit the manufacture of lithium batteries in the United States but will stymie the development and growth of the many downstream industries that design, manufacture, and operate products powered by lithium batteries. Those downstream industries collectively contribute more than 20x the gross domestic product and jobs contributions of the battery industry alone.
- Building a robust and sustainable lithium battery manufacturing base in the United States will require addressing a number of challenges that have depressed investment in the domestic lithium battery supply chain to date. It will also need to respond to the aggressive actions of competing nations that recognized the importance of lithium battery technology early on.

Li-Bridge recommends 26 specific actions to address the U.S. deficiency in lithium battery technology development and manufacture. These actions fall within five broad objectives:

Objective 1: Improve investment attractiveness of U.S.-based lithium battery technology and material production through expanded and better designed supply- and demand-side incentives

Objective 2: Support research, enable product and business model innovation, and accelerate pathways to commercialization through investments in R&D and validation & scaling capabilities

Objective 3: Help U.S. companies secure access to critical minerals, energy material supplies (virgin and recycled, domestic-and foreign-sourced) and low-carbon infrastructure

Objective 4: Address know-how gaps by investing in workforce training

Objective 5: Establish an enduring U.S. public-private partnership to support the development of a robust and sustainable lithium battery supply chain in North America

[1] BCG analysis

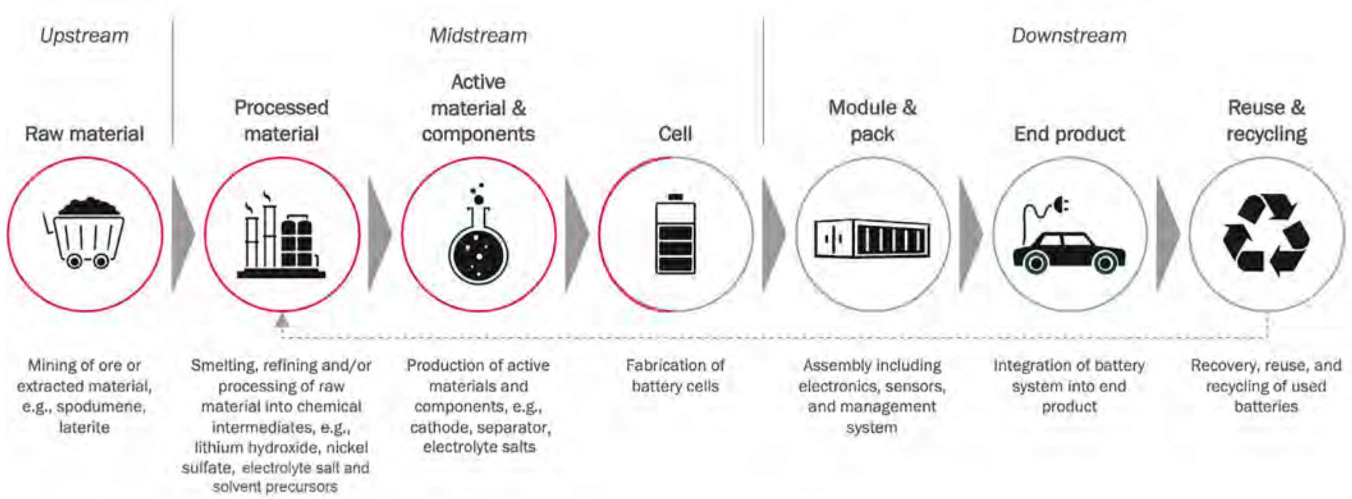
I. The Problem

Demand for lithium batteries is set to grow rapidly, driven primarily by the increased adoption of electric vehicles (EVs) and energy storage systems (ESSs) on the electrical grid. Global demand is expected to increase by more than 5x and U.S. demand by nearly 6x by 2030.[2] Despite this massive growth in lithium battery demand, the United States is projected to remain highly import-dependent.

The U.S. continues to be an innovation powerhouse for advanced battery materials, as partially credited by the U.S. Department of Energy (DOE) investments in research. However, without a comprehensive industrial strategy, today, the U.S. industry captures less than 30% of the economic value of each battery cell on the U.S. market, equating to approximately $3 billion value-added and 16,000 jobs. By 2030, if the "business as usual" case continues, the U.S. industry will capture slightly more of the U.S. market: about 30% domestic value-added, representing $16 billion value added and 60,000 jobs.[2] The remaining 70% value-added will come from imported materials, components, and cells. By comparison, China-based companies capture 90% of the economic value of each lithium battery cell consumed in China.

The United States relies (and, without intervention, will continue to rely) on a global lithium battery supply chain that is highly vulnerable to disruption, as seen in **Figure 1**. Two issues account for this vulnerability. First, global manufacturing capacity for batteries and battery materials is highly concentrated. China controls the largest global capacity share: >75% of cell production, >70% of processed energy material production, and >60% of energy materials purification and refinement.[3] Second, several raw minerals essential to batteries (particularly lithium, nickel, and copper) are forecasted to be in short supply globally over the next decade as demand grows faster than extraction capacity. Global competitors have spent the last decade buying up much of this limited supply.

Figure 1 Lithium battery supply chain: Gaps in upstream and midstream activities threaten U.S. economic security



1. Segments highlighted in red indicate significant gaps in US supply chain 2. "Cell" manufacturing partially highlighted to signal gap in manufacturing of next-generation cells
3. "Reuse & recycling" important to addressing "Raw" and "Processed" materials gap

[2] BCG analysis. Based on 2030 U.S. cell demand representing $52 billion and 165,000 jobs
[3] International Energy Agency. (2022). "Global Supply Chains of EV Batteries."

70% of the mining sector in the Democratic Republic of Congo (DRC). The DRC is the world's largest producer of cobalt, a material critical to the manufacture of most lithium batteries.[4] This combination of geographic concentration of battery manufacturing capacity and tight global supply of raw energy materials poses a significant risk to U.S. national and economic security.

Recent U.S. federal policy actions—i.e., the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA)—should meaningfully accelerate U.S. demand for lithium battery components and materials and spur the build-out of new North American production capacity. But these actions alone will not be sufficient to overcome the significant know-how, critical minerals, and energy materials access advantages that other countries have accrued.

II. The Need for Action

Absent government intervention, the U.S.'s high dependence on vulnerable global supply chains for lithium battery materials and components threatens U.S. economic power, national security, and climate goals:

Economic power: Risk to the U.S. economy goes well beyond the battery market itself. Lithium battery technology will be a key component and likely driver of a variety of products, devices and technologies that will shape the global economy of the 21st Century. These include light and heavy vehicles, renewable energy storage, consumer electronics, medical devices, weapons systems, electric drones, airplanes and ships, and almost certainly a large number of advanced products and devices that have yet to be developed. The manufacture, sale and servicing of those products and devices will likely account for more than 20x the lithium battery industry's gross domestic product and jobs.

National security: U.S. national security will remain endangered if the U.S. military continues to be significantly reliant on foreign sources of advanced batteries. The U.S. military today does not have direct, domestic access to the most advanced lithium batteries and chemistries to power its troops, vehicles, bases, and weapons systems. Foreign countries, including some that are potential adversaries, also control the upstream and midstream supply chain for those batteries.

Climate goals: Without reliable access to lithium battery technology, the U.S. simply has no chance of meeting the goals of reducing greenhouse gas emissions by 40% by 2030 or achieving net zero emissions by 2050. The U.S. endangers its position on the global stage if its climate targets are missed or if it is overshadowed by other countries.

To protect U.S. security and critical interests on several fronts, the U.S. government must act immediately to support the timely development of a North American lithium battery supply chain based on U.S. know-how and free from the threat of foreign supply constraints.

III. The Li-Bridge Initiative

The History and Purpose of Li-Bridge

In June 2021, the White House released its 100-day Supply Chain Review Report under Executive Order 14017, detailing the need for a national strategy for a robust and sustainable U.S. lithium battery supply chain. That same month, the Federal Consortium for Advanced Batteries (FCAB), a collaboration of several federal agencies with a stake in lithium batteries, published its National Blueprint for Lithium Batteries, outlining a national strategy for developing a robust and sustainable lithium battery supply chain. Recognizing the important role that industry must play to execute the strategy, the DOE asked Argonne National Laboratory (ANL) and three U.S. trade associations—NAATBatt International (NAATBatt), New York Battery and Energy Storage Technology Consortium (NY-BEST), and New Energy Nexus (NEX)—to convene leading experts in lithium battery technology from throughout the North American industry in order to provide their advice to the U.S. government. The project to convene industry experts and synthesize their recommendations is called the Li-Bridge initiative.

[4] Reuters

The Composition of Li-Bridge

Pursuant to the DOE's request, ANL, NAATBatt, NY-BEST, and NEX reached out through their extensive networks and identified leading experts in the business and technology of lithium battery manufacturing in North America. The organizations convened as part of Li-Bridge comprise companies representing more than 1 million employees and greater than $900 billion in annual revenue globally and include a diverse cross-section of the lithium battery supply chain, including:

- Upstream participants, including miners and refiners of critical minerals and energy materials
- Midstream participants, including cathode, anode and electrolyte materials producers, cell, and cell component manufacturers
- Downstream and end-of-life participants, including pack manufacturers, end product manufacturers (including major automobile manufacturers), electric utilities, and battery repair and recycling companies
- A wide range of company sizes, from large multinationals to startups

Industry participants included a variety of professions and job functions including engineers, scientists, executives, and labor management. The industry participants were supported by representatives from academia (including one Nobel Prize laureate), six national laboratories and Boston Consulting Group (BCG), one of the leading management consulting firms in the world.

The Li-Bridge Process

Gathering participants' inputs and formulating the recommendations took place over a series of all-day forums conducted over a 6-month period. Each forum focused on a distinct set of topics and built upon prior work. Forums consisted of group discussions, breakouts, and polls facilitated by BCG. Leading up to each forum, participants worked as part of a committee tasked with a specific focus area. The major activities performed by participants through the committees and forums included:

- Analyzing future U.S. supply and demand for cells, materials, and workforce
- Defining ambitious but achievable goals for the U.S. industry
- Identifying challenges holding back investment in the U.S. lithium battery ecosystem
- Drawing lessons learned from other countries to inform and inspire U.S. adoption of best practices
- Developing recommended actions for how to achieve the stated goals

This report synthesizes the findings and recommendations of the Li-Bridge initiative based on the four forums and associated committees' work to date.

IV. Li-Bridge's Goals for the U.S. Lithium Battery Industry

FCAB's vision

The National Blueprint for Lithium Batteries, produced by the FCAB in 2021, outlined a vision for the U.S. lithium battery supply chain. It states:

> *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.*

The Li-Bridge organizations fully support this vision. But Li-Bridge notes that satisfying this vision by 2030 will be challenging, given the industry's present state. Li-Bridge participants outlined a pathway for industry to achieve this vision by defining two goals: interim (by 2030) and long term (by 2050).

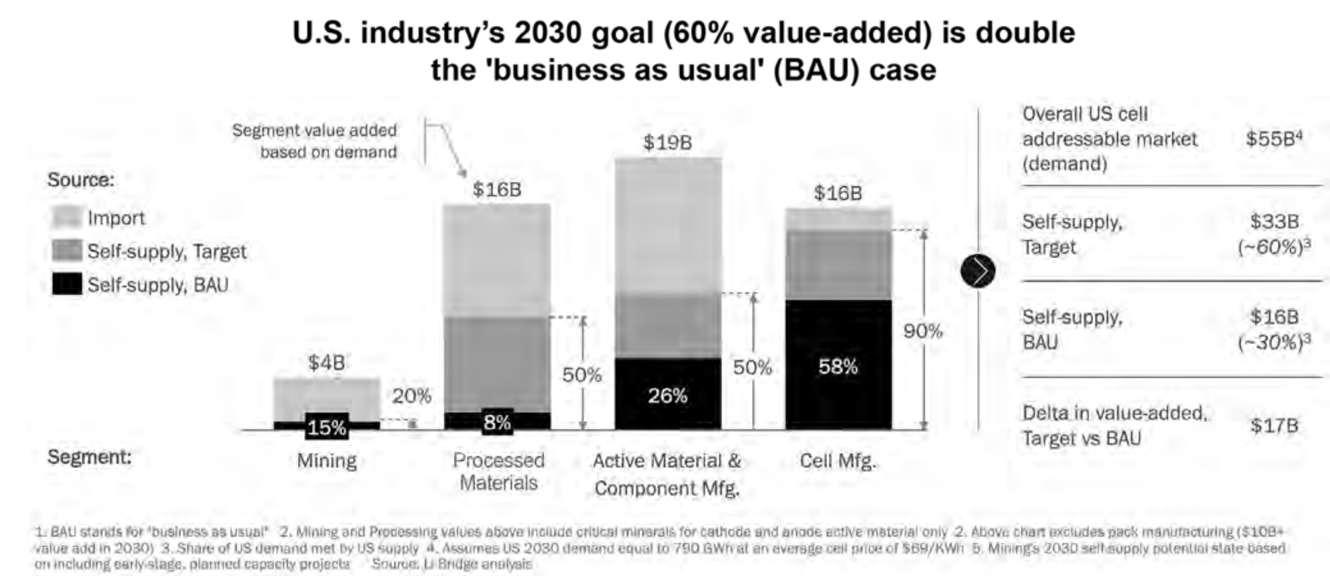
Li-Bridge's 2030 Goal

Majority domestic value-added

Li-Bridge believes that by 2030 the United States can capture 60% of the economic value consumed by U.S. domestic demand for lithium batteries ($33 billion value-added; 100,000 direct jobs[5]), up from the 30% domestic value-added most likely to result from doing business as usual. This 60% domestic value-added is Li-Bridge's 2030 goal, as seen in **Figure 2**. The Li-Bridge 2030 domestic value-added goal would add approximately $17 billion in direct economic benefits and 40,000 direct jobs to what would otherwise result from a business-as-usual scenario, without adoption of Li-Bridge's recommendations. Li-Bridge does not believe the U.S. can achieve complete lithium battery supply chain independence by 2030. But Li-Bridge does believe that U.S. industry can capture a majority of the value of lithium battery cells consumed domestically.

Figure 2 U.S. industry's 2030 target state (60% value add) is double BAU case

Annual incremental $17B value-add contribution implied in potential state requires overcoming key barriers to industry



[5] Figures include supply chain segments from mining to cell manufacturing without even including pack manufacturing

Achieving the Li-Bridge 60% domestic value-added goal for 2030 assumes the following domestic value-added share in each step of the supply chain:

- **Cell Manufacturing.** Approximately 90% of lithium battery cells consumed in the U.S. are manufacturing in the U.S.
- **Active Material and Inactive Component Production.** Approximately 50% of the active materials (including electrodes and electrolyte salts, and electrolyte solvents), and inactive components (e.g., separators) used in lithium battery cells consumed in the U.S. in 2030 are manufactured in the U.S.
- **Material Refining and Processing.** Approximately 50% of the chemical precursor materials used in lithium battery cells consumed in the U.S. are manufactured in the U.S.
- **Raw Material Production.** Approximately 50% of the raw lithium supply used in lithium battery cells consumed in the U.S. is produced from North American sources, virgin or recycled.

Due to long development timelines of raw material projects, Li-Bridge recognizes that the fourth goal listed above currently has the lowest probability of being achieved by 2030.

Recent new government support for lithium battery supply chain projects announced since the start of the Li-Bridge initiative have made the Li-Bridge 2030 goal even more attainable than Li-Bridge participants had assumed at the inception of the initiative. The 21 projects across the battery supply chain announced October 2022[6] as having been awarded $2.8B in grants under the IIJA are estimated to increase domestic value-added by 5-10% on top of the 2030 "business-as-usual" case projection.[7] But closing the remaining gap to the Li-Bridge 2030 goal of 60% domestic value-added will require the IRA's incentives plus additional actions by the government and by the industry.

Li-Bridge's 2050 Goal

Effective self-sufficiency and export opportunities

Li-Bridge believes that by 2050, the U.S. industry should be able to self-supply nearly 100% of the domestic need for lithium battery technology. By 2050, most of the energy materials needed to satisfy domestic demand should come from lithium batteries recycled in the United States. Given sufficient investments in lithium battery know-how and battery technology innovation, Li-Bridge believes that by 2050, U.S. companies can become a global power in the lithium battery industry and a major exporter of finished batteries and battery-related technology to the world.

[6] DoE BIL Battery FOA-2678 Selectee Fact Sheets (energy.gov)
[7] BCG analysis of FOA selectees, DOE BIL Battery FOA-2678 Selectee Fact Sheets (energy.gov)

V. Key Challenges Holding Back U.S. Industry Today

Li-Bridge identified eight key challenges that are preventing the development of a robust and sustainable lithium battery supply chain in the U.S. The policymakers, legislators, and industry representatives must address these challenges in order to achieve the Li-Bridge 2030 and Li-Bridge 2050 goals.

Li-Bridge believes that three of the eight challenges deserve special attention.

The Top 3 Challenges

CHALLENGE1 : Insufficient Return on Investment on Long-Term Projects

U.S.-based projects related to the lithium battery supply chain have historically had difficulty meeting the internal rate of return (IRR) and payback period requirements of U.S. investors.[8] Multiple factors contribute to the industry's unattractive IRR relative to other investments, including uncertainty regarding the scaling of production and uncertainty about the time requirements of regulatory approval. (This is in itself a priority challenge, described in the next section.)

The fundamental challenge is that projects along the battery supply chain require high initial investment in R&D, equipment, project construction, etc. followed by lengthy and expensive qualification and production scale-up periods.[9] These factors make them less attractive to investors than alternative opportunities in less capital-intensive industries.

Li-Bridge participants report that while many battery-related projects can be cash flow positive, they often have difficulty providing the 15% or greater return on capital employed (ROCE) that prospective U.S. investors tend to seek.

Differences in business culture across geographies also hinder U.S. investment. Korean, Japanese, and Chinese investors (home of the leaders in lithium-based battery production today) generally take a longer-term view than U.S.-based investors and are more willing to accept the lack of short-term return. Consequently, Asian investors fund a disproportionate share of U.S. battery-related projects. This has historically resulted in the transfer of much U.S.-based know-how and battery-related intellectual property offshore.

Boston Consulting Group estimates that more than $100 billion[10] of cumulative incremental investment in the U.S. battery supply chain—from new mines to cell-manufacturing facilities—will be required to meet Li-Bridge's 2030 domestic value-added goal. For reference, the IIJA has committed to funding over $7 billion in U.S. battery supply chain projects, which, with a cost match pledged by the industry,[11] represents approximately at least $14 billion in domestic capital expenditures. Separately, the Dallas Federal Reserve estimates another $40 billion in private funding[12] has been committed via recently announced U.S. projects.

Accordingly, nearly half of the capital investment required to meet Li-Bridge's 2030 domestic value-added goal for the United States is not in place—and this missing private investment needs to be put in place soon given the long development timelines. But investment conditions must be improved and investor expectations appropriately managed to unlock this additional capital.

CHALLENGE 2: Lengthy and uncertain timelines to secure permits and project approval, especially upstream

Li-Bridge participants report highly unpredictable timelines for securing permits and approvals in the United States relative to much of the rest of the developed world. Unpredictable timelines are most pervasive for critical mineral projects. But the unpredictability of permitting and project approvals limits potential investment in projects across the lithium battery supply chain. Several Li-Bridge participants cited delays in their projects ranging from six

[8] Does not consider the impact of 2022 IRA tax credits
[9] A typical 40 GWh cell-manufacturing facility costs >$5 billion and takes five years to progress from site selection to 80% capacity output, assuming upstream capacity already exists; a typical sedimentary lithium mine takes 10+ years from exploration to production stabilization (according to industry experts)
[10] BCG analysis of the cumulative incremental capital investment required to meet industry's 2030 domestic value added goal for the U.S. market; includes mining through cell manufacturing
[11] DOE Funding Opportunities Exchange, DE-FOA-0002677
[12] Dallas Federal Reserve, Oct 2022

months (cell manufacturing and grid energy storage projects) to a full decade (mining projects). These delays arise from proceedings at all levels of government.

Three factors account for lengthy and uncertain permit and approval timelines: opaque bureaucratic decision-making absent firm deadlines, an inconsistent appeals process, and resistance from local community groups:

Bureaucratic Process. U.S. battery-related projects often require multiple studies to obtain multiple permits, frequently with opaque or ever-changing criteria. Permits are administered by multiple agencies and/or different stakeholders within an agency, often involving multiple handoffs among understaffed regulatory personnel. Decision parameters are often unclear: it can take months—or typically years—to reach a decision, and multiple agencies with potentially conflicting timelines or mandates can be involved.

Securing a mining permit in the United States takes seven to ten years according to a 2015 report by SNL Metals & Mining.[13] By comparison, permitting in Australia, a country with similarly complex stakeholder interests, takes, on average, two years. Four major differences in Australia can account for this discrepancy: mining companies in Australia are responsible for conducting their own environmental reviews, there is a clear timeline for government to respond to the permit application, federal and state agencies are delineated, and the ownership and responsibility of each agency are clearly defined.

Appeals Process. The start-and-stop nature of securing and maintaining a permit creates additional industry challenges. The slow nature of a court challenge to an existing permit can result in the permit expiring before the court reaches a decision. The applicant must then start from the beginning and go through the permit application process again, including the re-performance of environmental impact studies. Major permits, which require numerous technical judgments by an agency, may be voided if a judge disagrees with any aspect of the permitting process. Participants also expressed frustration about their inability to "blue pencil"[14] applications to address individual deficiencies rather than having to start the application and approval process from the beginning to address an objection. The broad discretion of courts to slow or reverse administrative decisions for any reason is also a source of frustration.

Community Resistance. Li-Bridge participants report scrutiny and opposition from community groups for new projects, particularly mining projects. The industry acknowledges that community skepticism of new projects is often based on the mining industry's poor historic record within certain communities, particularly indigenous and minority populations, which typically does not reflect current best practices among resource developers in the U.S. New critical minerals and energy materials projects in the United States will need a social license to operate in those communities. At the same time, communities with jurisdiction over natural deposits will need to consider and comply with the larger issues of national security, economic prosperity, and climate change in deciding whether to support new projects in their jurisdictions. Building productive and equitable partnerships between energy materials producers and affected communities will be essential to building out the U.S. lithium battery supply chain.

The lengthy and unpredictable permitting and approval process in the United States reduces the average value of a mining project by one-third.[15] Longer delays can make mining projects financially unviable, even before the costs of litigation are considered. Speeding the path to successful permits has three winning benefits for the industry: faster relief from a global supply constraint, a faster buildup of U.S. self-supply, and an enabler for the United States to commercialize more advanced and lower impact production technologies.

CHALLENGE 3: Lack of Access to Critical Minerals and Raw and Processed Energy Materials

Several Li-Bridge participants anticipate a worldwide shortfall in supplies of critical minerals and energy materials within a four-to-twelve-year time frame (before new foreign and domestic sources of supply can be brought online). The governments of other countries have been actively supporting efforts by their private companies to tie up available sources of supply internationally, outcompeting U.S. firms. Chinese companies with the support of the Chinese government have secured a dominant position in several of these overseas assets. China-based mining and battery giants have invested in several international development-stage lithium projects. China-backed companies own or have stakes in 80% of the Democratic Republic of Congo's cobalt-producing mines, partly via minerals-for-infrastructure deals coordinated by government parties.[16] China-based companies have also taken investment stakes in leading international mining companies, such as China-based Tianqi Lithium's partial ownership of Chile-based SQM. Underlying each of these ventures is strong state support and a willingness to pay a premium over fair market prices to secure control over critical minerals and fulfill a public-private strategic vision of vertical integration.[17]

U.S. lithium battery manufacturers and users are at a severe disadvantage in obtaining access to critical minerals and energy materials relative to companies based in certain countries. U.S. government intervention is necessary to "level the playing field", especially if U.S.-based companies operating internationally are expected to adhere to stricter environmental, social and governance rules.

Other Industry Challenges

CHALLENGE 4: Insufficient benefits for customers (OEMs) to "buy local" and pay more for U.S.-made intermediates

Li-Bridge participants believe that without changes to U.S. government policies, U.S.-based battery makers and original equipment manufacturers (OEMs) will largely choose to import intermediate materials from outside the United States in order to take advantage of their lower landed costs. On average, Li-Bridge participants estimate that U.S.-produced battery materials and components have landed costs that are 10–20% higher than similar materials imported from Asia.[18] OEMs typically have no incentive to pay this premium for U.S.-made products.

CHALLENGE 5: Lack of U.S. R&D- and pilot-scale line capacity for the commercialization of new technology

Li-Bridge participants report a shortage of shared pre-commercial-scale production facilities for lithium batteries in the United States at both the R&D-scale (<1 MWh/year) and pilot-scale (1–500 MWh/year) production capacity ranges. (Pre-commercial scale includes R&D-scale and pilot-scale production lines for product development and validation.) Industry reports that wait times to access an R&D-scale line average >12 months in the United States versus one month in China and the European Union. Participants also report that, currently, there are no shared pilot-scale battery manufacturing facilities in the United States. The lack of shared pilot-scale facilities increases costs and extends product development and qualification timelines for producers at every step of the supply chain. This is particularly true for small and mid-sized companies seeking to commercialize new active materials, components, and processing equipment. The lack of easy access to pre-commercial scale production facilities results in reduced commercial value of innovation, missed opportunities for leap-frogging technology and process innovation, slower momentum in building workforce know-how, and the leakage of intellectual property overseas.

CHALLENGE 6: Lack of domestic technical know-how, especially in midstream activities

The U.S. lithium battery industry currently possesses limited skilled worker training in high-volume production, particularly in midstream activities, and will need to ramp up the workforce development required to meet future battery demand. Expertise in large-scale production is needed across the entire battery supply chain. But the most acute need is in midstream segments such as battery-grade material processing, active material and component production, cell manufacturing, and end-of-life battery logistics. Meeting Li-Bridge's 2030 domestic value added goal for increased U.S. self-supply will require 120,000 additional workers across the battery supply chain.[19] The U.S. battery industry's limited workforce development in large-scale lithium battery and battery materials manufacturing could prove a serious obstacle to the 2030 goal.

CHALLENGE 7: Limited suitable sites served by reliable clean energy

Access to reliable and clean electric power is a key requirement for building up the lithium battery supply chain in the United States. Although the U.S. has abundant, inexpensive land available for industrial development, sites that are truly shovel-ready for projects with large electricity demands are in surprisingly short supply. Extending existing electricity infrastructure to new industrial sites is often a slow and cumbersome process. Lack of access to clean electric power is also a serious issue. U.S. manufacturers take their corporate decarbonization goals seriously and need sites that have access to large amounts of clean, reliable energy in order to meet them. This is a particularly important issue for companies based in or selling products into Europe, where corporate carbon emissions are carefully tracked and regulated. Companies are finding that they can locate their energy-intensive manufacturing facilities in Canada, for example, where clean hydropower is abundant and where companies can still maintain nearby access to U.S. markets. Participants also report challenges with transportation infrastructure, particularly bottlenecks at ports delaying shipments of critical equipment and supplies.

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[13] National Mining Association, SNL Permitting Delay Report

[14] A legal concept where a portion of a contract is invalidated but the remaining contract remains valid, as opposed to the entire contract being invalidated

[15] National Mining Association, SNL Permitting Delay Report

[16] NYTimes

[17] Politico

[18] Per Li-Bridge topic committee analysis; primarily because of lower domestic know-how, higher labor costs, and higher environmental and social standards

[19] Includes raw material through pack manufacturing

CHALLENGE 8: A lack of domestic suppliers of key manufacturing equipment and reliance on protective, overbooked foreign suppliers

One of the most important gaps in the U.S. lithium battery supply chain is the lack of domestic equipment and tooling suppliers that make machinery used in the manufacture of lithium batteries and battery materials. Manufacturing equipment makers control vital know-how in lithium battery technology. The absence of significant makers of lithium battery manufacturing equipment (such as winding, stacking, or formation and grading systems) in the United States places U.S. manufacturers of lithium batteries at a serious disadvantage. Asian cell manufacturers usually work very closely with co-located machine manufacturers to improve production processes. U.S. battery manufacturers do not have that option. In addition, U.S. cell and materials manufacturers find themselves at the end of a long line in waiting for delivery of machinery or access to new, innovative equipment. Foreign machine makers tend to prioritize customers in their home markets—Li-Bridge participants report a lead time of 18 to 48 months for buying electrode coating machines from Asia. U.S. manufacturers are often unable to obtain the latest generation of manufacturing equipment until several quarters after that equipment has been delivered to manufacturers in East Asia.

VI. Guiding Principles

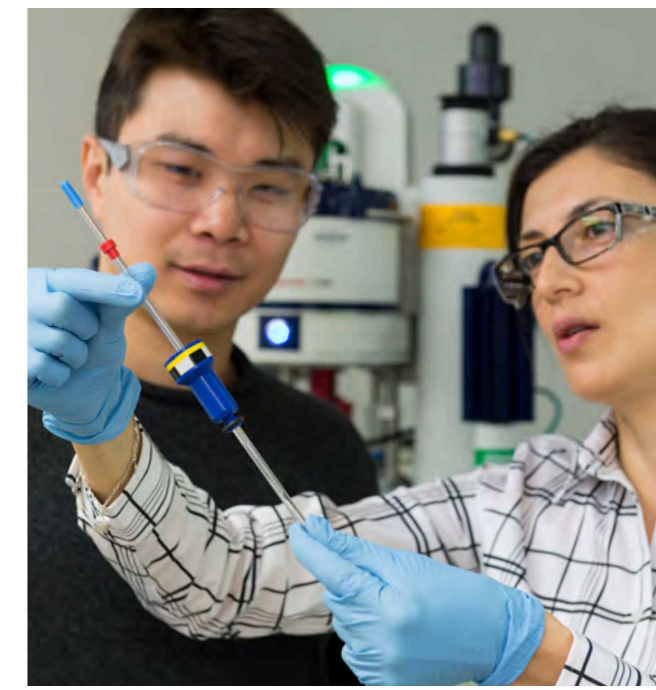
The following set of principles helped guide the development of Li-Bridge's recommendations:

There is an urgent need to strengthen the U.S. lithium battery supply chain. Decisions being made today on where to locate capacity will lock in supply chain flows and business ecosystems for the next several decades. U.S. industry is already seeing the effects of market share shifts in a resource-scarce world. It is well documented that the United States is far behind other countries and must act quickly if it is to enable U.S.-based companies to become world leaders in battery technology and supply chains.

Solving this challenge will require long-lasting, sustained policy interventions that transcend political administrations and congressional power dynamics. Supply chain changes take time. Downstream players cannot switch supply chains overnight. Upstream suppliers can require several years or as long as a decade to bring new capacity online. Unpredictable and ever-changing regulatory, political, and natural environments create unstable demand and supply signals, hindering investment and commercialization.

Government has a key role to play in several areas, particularly in reducing regulatory complexity, forging international partnerships, and supporting innovation. Governments at the federal, state, and local levels have the unique ability to streamline and harmonize regulations that add costs and limit the speed of commercialization and growth (e.g., permits for mines or codes governing the transportation of waste batteries). At the federal level, the U.S. government is well positioned to help secure U.S. access to critical materials and equipment through international partnerships. The U.S. government is also well positioned to support innovation through continued R&D investment, which is essential for U.S. competitive advantage.

The United States must lean into its strengths to build a sustained competitive position. The culture of innovation and entrepreneurship in the United States is unrivaled in the world. Where U.S. companies have fallen behind is in the manufacturing of products that have emerged from that innovation. The U.S. must reinvigorate its battery manufacturing sector and double down on investment in foundational science and use-inspired research to uphold the culture of innovation. The U.S. must also leverage the large size of its market which can support scale efficiencies in domestic producers.



VII. Li-Bridge Objectives and Specific Recommendations

Following consultation with the leading experts in lithium battery technology in the U.S. industry, academia and the national laboratory systems, Li-Bridge has adopted a series of recommendations to the U.S. government and to the U.S. industry.

Li-Bridge believes that adopting these recommendations will help the United States achieve Li-Bridge's 2030 and 2050 Goals discussed earlier in this paper. The individual recommendations are organized around five recommended objectives for the U.S. lithium battery supply chain:

OBJECTIVE 1: Improve investment attractiveness of U.S.-based lithium battery technology and material production through expanded and better designed supply- and demand-side incentives

The U.S. government must take actions to enhance the expected returns on financial investments in U.S.-based lithium battery supply chain-related projects (e.g., battery materials, components, cells, or manufacturing equipment) and reduce the perception of demand uncertainty in the U.S. battery market. The IRA, particularly via tax incentives, should significantly improve the attractiveness of investments in the lithium battery supply chain. But more must be done to encourage investments that localize production and lithium battery manufacturing know-how in the United States. Li-Bridge believes that investment incentives should be allocated to favor the localization of production facilities, R&D and engineering staff in the United States, regardless of the ownership of the entity receiving the incentive.

OBJECTIVE 2: Support research, enable product and business model innovation, and accelerate pathways to commercialization through investments in R&D and validation and scaling capabilities

The United States must redouble its support for technological innovation, a key strength and competitive advantage of U.S. society. Additionally, the country must also better support the commercialization and manufacture of domestic battery innovations. The process and manufacturing equipment for producing battery cells and materials at commercial scale are ripe for innovation. Efforts to support the large-scale manufacture of battery technology should focus on manufacturing advanced and next-generation battery technologies.

OBJECTIVE 3: Help U.S. companies secure access to critical raw minerals and processed energy materials (virgin and recycled, domestic- and foreign-sourced) and low-carbon infrastructure

The United States must work simultaneously to encourage the development of minerals and materials mining domestically and to secure the supply of raw products from reliable trading partners abroad. An effective raw materials strategy must also include significant support for lithium battery recycling and developing a battery materials export control policy. Li-Bridge participants identified lithium and nickel as the two most pressing critical minerals on which to focus, yet there is a risk that any of the critical minerals used in lithium batteries or battery production could prove to be a bottleneck in the years ahead absent continued monitoring and investment.

The country must also continue investing in the nation's ports, railways, and clean energy infrastructure to support cost-efficient logistics and enable the export of U.S.-made goods to carbon-regulated markets. The manufacturing and infrastructure deployment should align with community goals and energy justice principles.

OBJECTIVE 4: Address know-how gaps by investing in workforce training

The education of skilled battery technicians and engineers is essential for establishing, automating, and continuously improving domestic manufacturing and for bridging gaps in the U.S.'s supply chains. The United States must invest in creating quality, place-based technical training programs to prepare the future workforce. Specialized battery training programs will provide the interdisciplinary skills needed by American workers to chart fulfilling careers and avoid becoming mere low-paid assemblers of imported products. Li-Bridge believes that community colleges, apprenticeships, and trade schools can play a particularly important role for staffing the processing and manufacturing industry. Collaboration among higher-education institutions and community colleges should be encouraged.

OBJECTIVE 5: Establish an enduring U.S. public-private partnership to support the development of a robust and sustainable lithium battery supply chain in North America

Building a robust and sustainable lithium battery supply chain across the United States and its allies will require effort from multiple state, local and federal government agencies as well as private industry. Many of those efforts are already underway. But there is a real danger that those initiatives will be less effective than they could be because of lack of coordination, oversight, and accountability for results. A formal public-private partnership with a central program management office would do much to provide that coordination, oversight and accountability and ensure that those efforts are as efficient and effective as possible.

Li-Bridge recommends the following specific recommendations within each of the five objectives identified above:

OBJECTIVE 1: Improve investment attractiveness to catalyze new capacity investment in the United States

1.1. Capex incentives: Expand incentives to offset capex for upstream, midstream, and downstream capacity, including manufacturing equipment suppliers, with preference given to domestic suppliers and next generation technologies

1.2. Production incentives: Expand incentives to offset production-related costs (e.g., production tax credit)

1.3. R&D incentives: Conduct a fast-track study of R&D tax treatment and incentives to make investment in the intensive battery industry more attractive to investors, and implement recommended actions

1.4. Demand incentives: Expand point-of-sale incentives to include medium- and heavy-duty truck EVs, buses, construction, agriculture, mining, ESS, and other electric off-road transportation such as aircraft. Attach domestic content requirements to promote the use of U.S.-based midstream and upstream production. The size, shape, and duration of expanded incentives should be calibrated to not exacerbate current supply scarcity in lithium-based battery supply chains.

1.5. Government procurement: Leverage government procurement programs to support next-generation technologies and provide advanced market commitments that reduce commercialization risk.

1.6. Insurance pools: Create insurance pools for battery cell, pack and battery material producers to hedge against the risk of product recalls and make it easier for new U.S. companies without large balance sheets to enter the automotive battery market and compete with established foreign suppliers.

OBJECTIVE 2: Support innovation and accelerate pathways to commercialization

2.1. R&D investment: Invest heavily in both applied and use-inspired basic science research related to lithium battery technology, materials, and manufacturing equipment and processes.

2.2. Pre-commercial-scale production lines: Define industry needs for R&D-scale (< 1 MWh/year) and pilot-scale (1-500 MWh/year) shared-access battery production lines to accelerate pathways to commercialization of new battery technology. Define and develop a sustainable business model for operating those shared-access facilities.

2.3. Standards: Promote the generation and codification of industry standards related to lithium batteries and the systems they power. This initiative should include harmonizing installation requirements for ESS across jurisdictions, defining standards for cost-constrained applications, such as electric micro-mobility, and new use cases such as electric vertical take-off and landing vehicles (eVTOLs), and revisiting ten-year capacity fade requirements for battery packs. Industry must also work to educate stakeholders about existing standards to avoid overlapping or competing regulations.

2.4. Commercialization support: Provide commercialization support to early-stage U.S. companies working to develop lithium battery related products, including access to commercial and technical advisors and assistance with patent filings.

OBJECTIVE 3: Help U.S. companies secure access to critical minerals, energy materials and low-carbon infrastructure

3.1. Permitting reform: Improve predictability in the permitting process (e.g., time limits, transparent criteria, lead agency), accelerate time to decisions, build community support, and harmonize regulations for mining/extraction and material-processing projects.

3.2. Critical minerals database: Expand and accelerate the creation of a national database of critical mineral resources (owner of mineral rights, required permits, local and state contacts) and gather data from existing mining and oilfield operations—then make this data strategically available through an online portal and interactive map. Similarly, develop a tracking dashboard that monitors and forecasts international supply chains.

3.3. Buying consortium: Develop a consortium of companies for purchasing critical battery-related minerals and materials from domestic and foreign sources—improving purchasing power and reducing risk via access to a more diverse pool of material suppliers.

3.4. Foreign partnerships: Support prioritized access to critical mineral mines in partner countries through financial support from the U.S. International Development Finance Corporation and continue to strengthen country-level cooperation, such as through the Minerals Security Partnership.

3.5. Circularity: Establish an industry-led waste battery end-of-life program, harmonize regulations for transporting waste batteries, and support the recovery and use of domestically recycled content.

3.6. Trade control: Recalibrate trade controls, such as the Wassenaar Arrangement, to encourage U.S. companies to develop high-energy-density solutions and compete for global business. Consider export controls on new and used energy materials to reduce leakage from the U.S. energy materials supply chain.

3.7. Critical minerals sea mining: Conduct definitive environmental studies on critical mineral sea mining that serve to remove uncertainty regarding U.S. company participation in sea-based mineral extraction and purchasing.[20]

3.8. Stockpile: Bolster the National Defense Stockpile for battery-critical minerals and materials in a manner that smooths commodity pricing cycles and does not exacerbate supply shortage or inflate raw material costs for U.S. industry. Stockpiling strategy will need to consider storage conditions, expiration dates, and use in government-procured energy storage applications, among other factors.

3.9. Infrastructure: Invest in more clean energy generation and upgrade port and rail systems in order to make U.S. lithium battery manufacturing more economically competitive.

3.10. Industrial zones: Select and designate special industrial zones for battery production to support the efficient clustering of battery-related manufacturing operations. Steer government financial support to those zones. Implement within those zones streamlined regulatory processes recommended by industry and approved by local authorities and communities. Favor locating industrial zones in regions where existing jobs are threatened by the clean energy transition. Assess co-locating battery production industrial zones with other types of advanced manufacturing, such as semiconductors or hydrogen, for increased synergies.

3.11. Community engagement: Develop a handbook for community engagement best practices, tailored to different communities, and deploy community engagement teams to build support and accelerate project approval.

[20] Politico

OBJECTIVE 4: Address know-how gaps

4.1. Curricula development: Assess the skills gap in U.S. lithium battery manufacturing and identify all existing training programs that can address that gap. Develop new educational/training curricula for degrees and certifications that will fill gaps in existing training curricula.

4.2. Curricula deployment: Implement workforce training and educational curricula for schools; implement upskilling for oil and gas workers, autoworkers, and other professions impacted by the clean energy transition.

4.3. Training support: Support training and educational programs to expand the talent pipeline (e.g., scholarship, apprenticeships).

4.4. Technical exchange: Implement international technical exchange program with targeted and time-limited visa expansion to promote the transfer of critical lithium battery know-how into the United States.

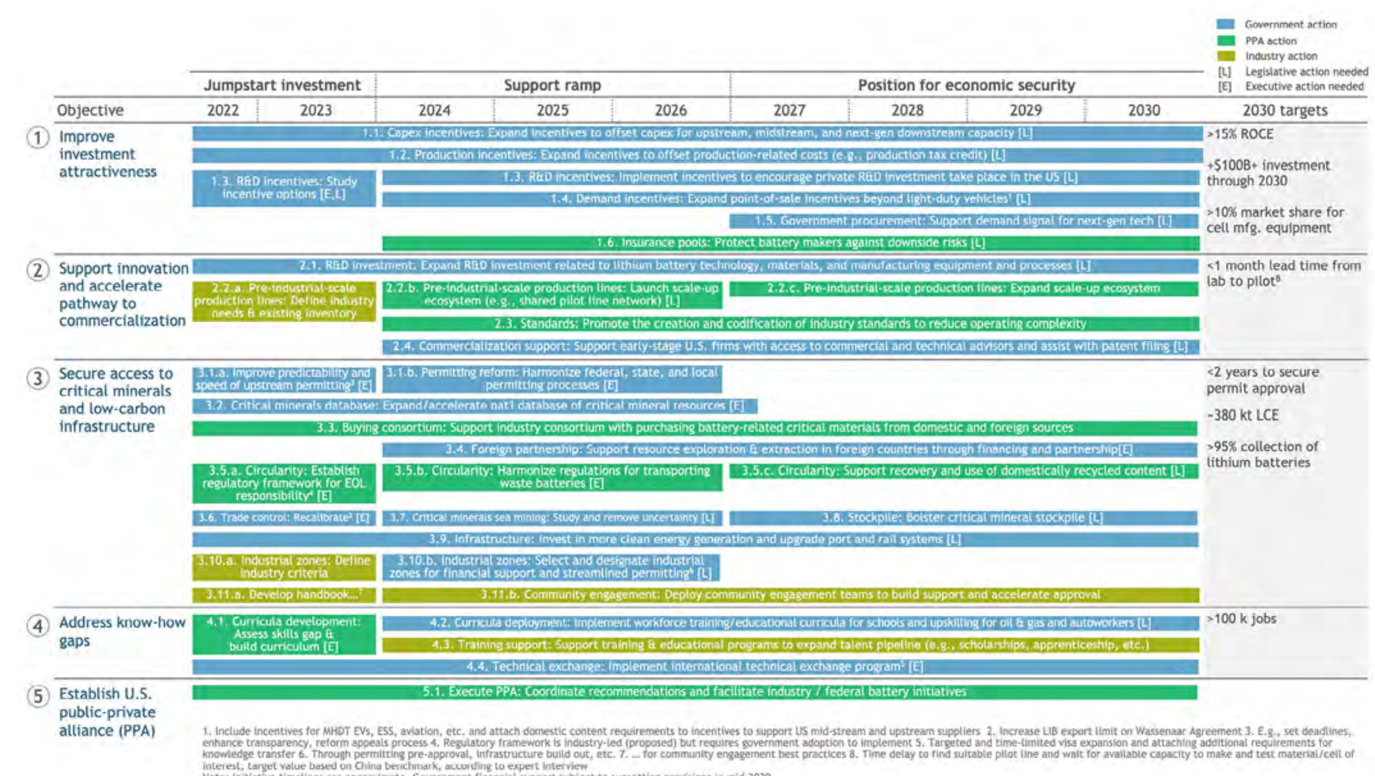
4.5. Catalyzing Council: Stand-up a National Battery Workforce Council comprised of industry, government, community organizations, academia, and workforce/labor intermediaries to coordinate and execute national battery workforce objectives.

OBJECTIVE 5: Establish an enduring U.S. public-private partnership for lithium battery supply chain in North America

5.1. Create an enduring coordinating body to execute the recommendations: Make Li-Bridge a formal public-private entity charged with coordinating and executing on the tasks recommended in this report. Create a central program management office to monitor and coordinate execution of the recommendations and to report progress on the development of the domestic lithium battery supply chain periodically to the federal government and coordinate collaboration with allies.

Figure 3 captures the roadmap of activities through 2030 across the five objectives and the associated interdependencies to achieve the stated targets.

Figure 3 Roadmap to strengthening U.S. battery supply chain through 2030



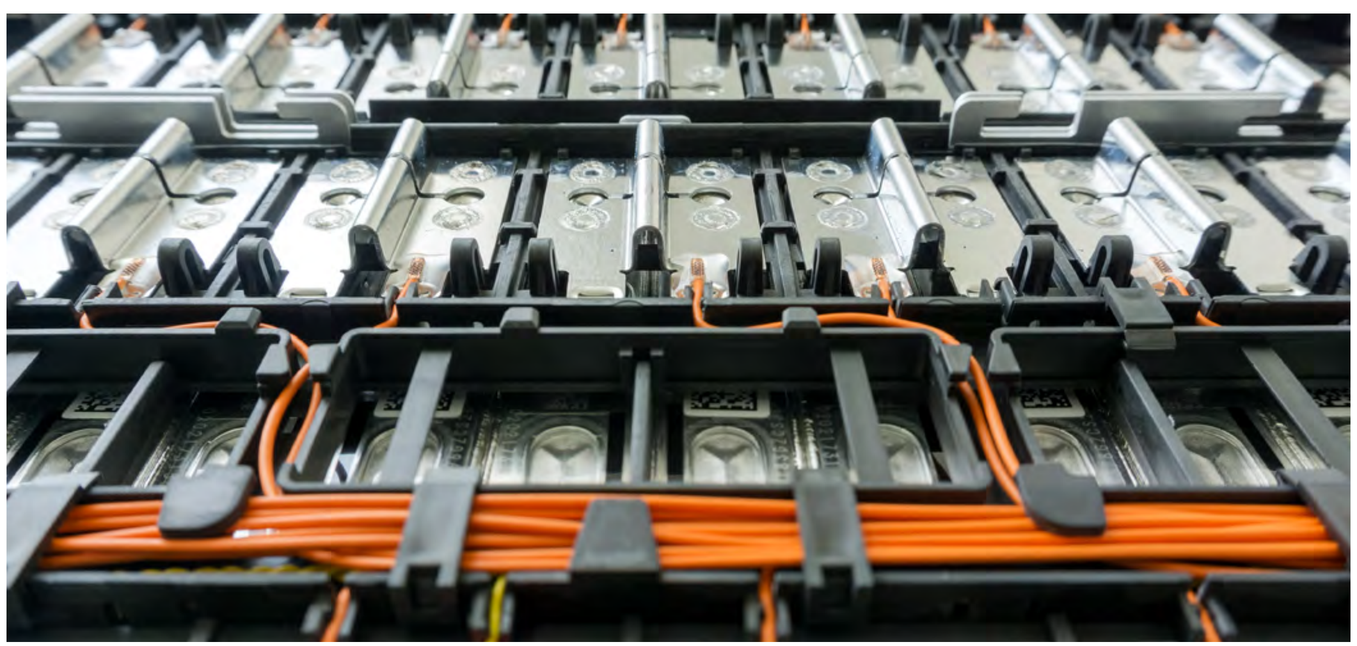
Evaluation of recommended initiatives against recent developments

The past year has seen many policy developments with implications for the U.S. lithium battery supply chain. The most significant are two laws, the Infrastructure Investment and Jobs Act of 2021 (IIJA) and the Inflation Reduction Act of 2022 (IRA). The provisions of these two laws align with many of the recommendations made in this report. **Figure 4** shows which recommendations the IIJA and IRA already address and where gaps remain.[21] Li-Bridge strongly recommends the U.S. Department of Treasury continue to consult with companies in drafting the implementation rules for the IRA's incentives and conditions to maximize new investment in domestic lithium battery development and manufacturing capacity.

In addition to the IIJA and IRA, many other policy actions have been implemented or announced recently, such as the American Battery Materials Initiative.[22] Li-Bridge expects these efforts to further support and implement some of the abovementioned recommendations.

Figure 4 IIJA & IRA provisions provide significant support for improving U.S. investment attractiveness and infrastructure, but gaps remain elsewhere

Li-Bridge recommendation pillar	Gap remaining after IIJA + IRA provisions	Comments on IIJA + IRA provisions
1) Improve investment attractiveness	◔	IIJA + IRA provisions largely cover Li-Bridge initiatives 1.1., 1.2., and 1.4. Industry excited by IRA tax credits, though uncertain about ability to meet sourcing requirements in EV tax credit
2) Support innovation & commercialization	◕	IIJA + IRA provisions provide little incremental funding for lithium battery R&D or commercialization and nothing for shared pilot-scale lines
3) Secure access to materials & infra	◕	IIJA + IRA provisions provide a significant boost to infrastructure and clean energy — but lack concrete actions on permitting reform and developing and securing access to critical mineral resources outside the US
4) Invest in people	◑	Few workforce development measures explicitly named; more efforts needed
5) Support public-private alliance	●	Not mentioned



[21] See appendix for more detail
[22] The White House

VIII. Immediate Next Steps for Key Stakeholders

U.S. Congress

- Pass permitting reform to accelerate critical mineral mining and processing projects.
- Appropriate funding for pre-commercial battery production facilities.
- Work with industry to create a consistent, unified national approach to lithium battery recycling.

U.S. federal agencies

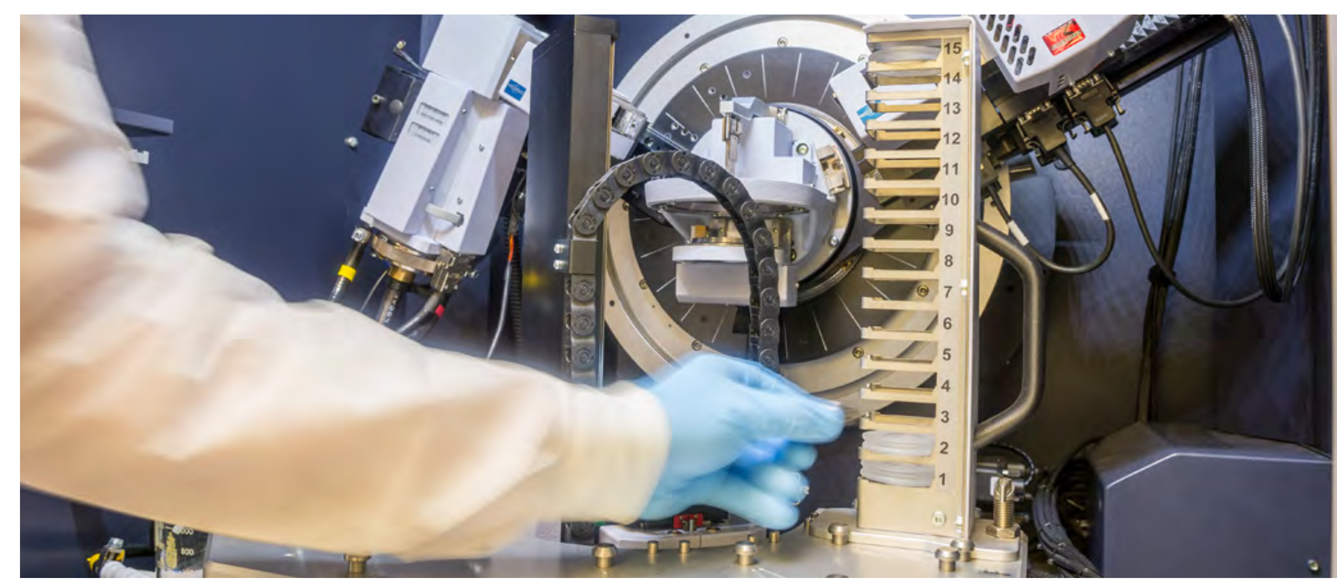
- Collaborate with Li-Bridge to implement the recommendations made in this report.
- Consult with the U.S. industry to draft effective implementation rules for the Inflation Reduction Act incentives to catalyze new investment in lithium battery development and manufacturing capacity, including electrodes and electrolyte salts, and electrolyte solvents.
- Direct R&D toward priority areas in partnership with the existing federal agencies (e.g., DARPA, ARPA-E), national laboratories, and manufacturing institutes while continuing to expand support for demonstration and deployment.
- Support the establishment of a National Battery Workforce Council dedicated to rapidly advancing the training and education of battery industry workers.

State/local governments

- Streamline and standardize permitting processes to accelerate critical mineral mining and processing projects; develop shovel-ready industrial zones for energy materials and battery cell production.
- Partner with industry to build support for battery-related projects among local communities.

Industry

- Continue to work together to further define industry needs (including workforce training needs), step up efforts to enact battery standards, and help shape solutions that will allow the U.S. industry to participate more fully and profitably in the manufacture of lithium battery technology.



IX. Final Word

By implementing the recommended actions outlined in this report, Li-Bridge believes, the U.S. industry can double its value-added share by 2030 (capturing an additional $17 billion in direct value-add annually and 40,000 jobs in 2030 from mining to cell manufacturing), dramatically increase U.S. national and economic security, and position itself on the path to a near-circular economy by 2050.

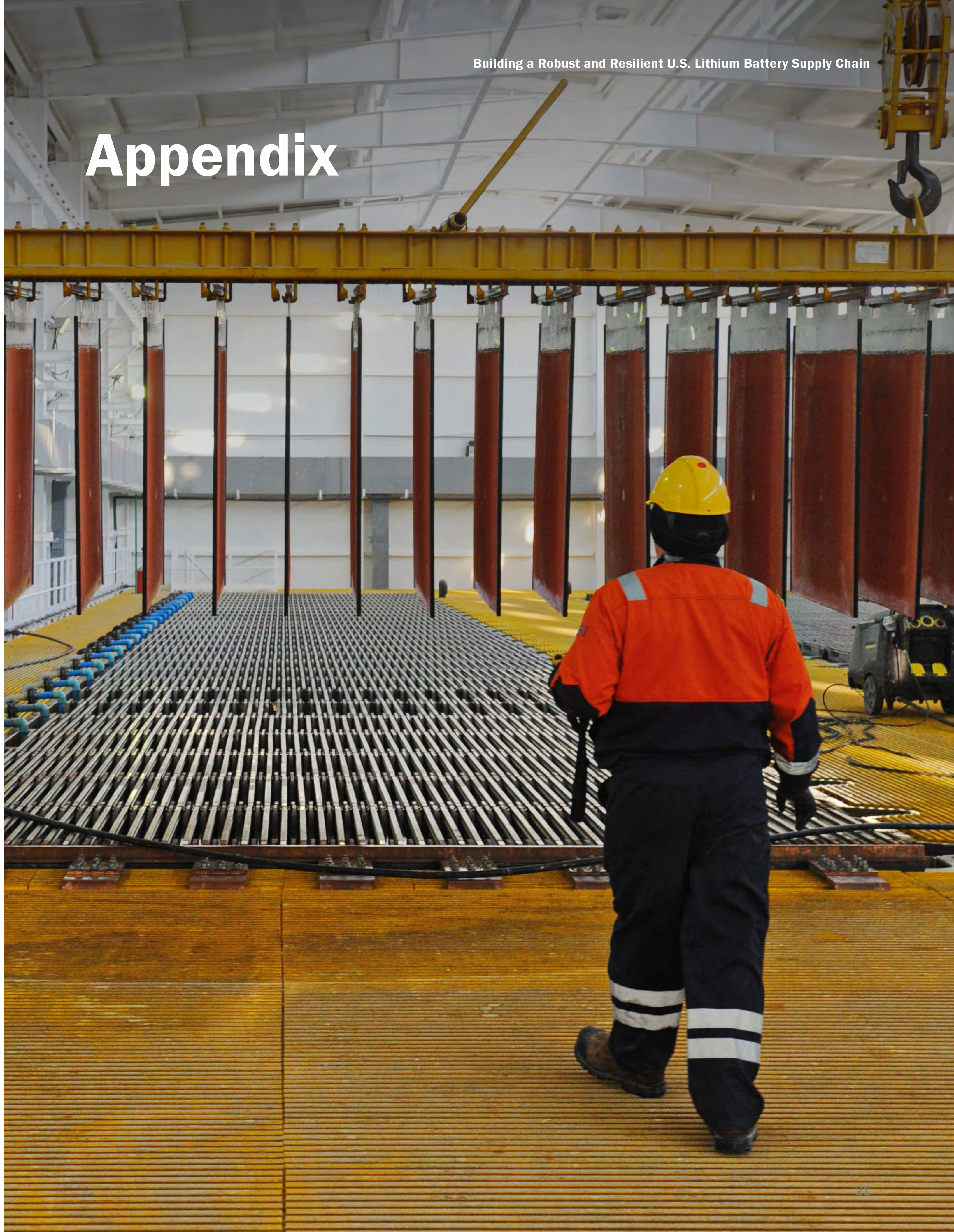
Li-Bridge is optimistic that the U.S. industry can build sustainable competitive advantages, overcoming any comparative disadvantages the United States may have in the form of higher costs or a lack of critical mineral resources and enabling the U.S. industry to thrive without perpetual government support. Li-Bridge believes the U.S. path to sustainable competitive advantage will rely heavily on continuing to build its capabilities in innovation and speed to commercialization. U.S. innovation and commercialization must occur in all forms (product, process, and business model), at all levels (breakthrough innovation and continuous improvement), and across all segments (upstream to downstream) to ensure enduring demand for U.S.-produced products. The United States must build upon its solid foundation in materials innovation today and develop strengths in new areas, such as manufacturing processes and equipment.

Li-Bridge's recommended initiatives support building sustainable competitive advantage in the United States in several ways:

- By jumpstarting U.S. capacity investment to gain know-how in high-volume manufacturing (**Objective 1**)
- By investing in R&D and shared pre-commercial production lines to develop and bring U.S. innovations to market more quickly (**Objective 2**)
- By securing access to critical minerals and materials to reduce risk to U.S. producers and customers (**Objective 3**)
- By investing in workforce development to ramp up production more quickly and drive continuous improvement (**Objective 4**)

Li-Bridge recommends that the U.S. government implement the actions recommended in this report and engage with industry through the Li-Bridge alliance to ensure the effective implementation of those actions. Doing so will put the U.S. lithium battery supply chain firmly on the path to achieving Li-Bridge's 2030 and 2050 goals and building sustainable competitive advantages.

Appendix



A.1. Expansion of “Other notable industry challenges”

CHALLENGE: Insufficient benefits for customers (OEMs) to “buy local” and pay higher cost for U.S.-made intermediates

Industry expects a large share of cell manufacturing and pack assembly to localize in the U.S. under current economic and regulatory conditions.[1] Yet, Li-Bridge participants do not expect the production of many battery intermediate goods, such as chemical precursors and certain active materials, to localize in the U.S. without policy intervention.[2]

Facilities in East Asia, Australia, and South America produce a majority of intermediate battery products today and serve as the benchmarks for establishing competitive U.S.-made supply. Global customers have established relatively mature supply chains to access these products. Most intermediate goods are easily shippable and have sufficient shelf life to enable international trade.

Finally, leading suppliers of intermediate battery products by market share are not U.S.-based companies.

The value proposition of U.S.-made intermediates: On average, Li-Bridge participants estimate that U.S.-produced battery materials and components carry 10–20% higher landed costs[3] than equivalent materials and components produced in and imported from Asia-Pacific. Several factors contribute to the U.S.’s higher cost position, including:

- **Limited know-how (largest factor):** The U.S.’s current immature position on the learning curve (i.e., experience with large volume production that improves production costs) translates to lower productivity, higher scrap rates, and a longer timeline to ramp up production to full capacity.
- **Higher labor costs:** Compared with China, U.S. labor costs are estimated to be 2–3x higher for engineers and 4–5x higher for semi-skilled workers.
- **Environmental, social, and governance standards:** U.S. producers face more stringent emissions and waste standards. However, this gap is expected to diminish over time as China increases its standards.

These disadvantages outweigh potential savings from the U.S.’s low-cost energy supply and lower cost outbound logistics to serve its domestic markets.

Industry participants report OEMs are unwilling to pay 10–20% more in direct pricing to have U.S.-made intermediates in their batteries. U.S.-produced intermediate goods generally do not provide meaningful other quantifiable benefits to compensate for their higher cost position such as highest quality or lowest embedded carbon. While there are operational benefits created by proximity such as closer collaboration and supply chain resiliency, switching costs are also related to an OEM’s time and effort to re-establish localized supply chains. Put simply, U.S. producers’ cost positions must improve.

OEMs are also not required to source locally to access U.S. markets. There were no domestic or North American content requirements for battery cell manufacturing or their end applications (e.g., EVs) prior to passage of the Inflation Reduction Act—outside of lithium-based battery solutions used in defense applications. So, producers of battery intermediate goods are wary of investing in U.S.-based production capacity for the sake of offering U.S.-made products.

What’s at stake: Intermediate materials and components contribute greater than 50% of the value add and jobs that comprise a battery cell. Announced production facilities for intermediate goods exceed 100 GWh annually and have billion-dollar construction price tags.

OEMs will continue to pursue an optimized global production footprint given the importance of cost, ship-ability of products, and inherent distance between the largest markets for finished products and where battery raw materials are found. The U.S. must become more competitive to attract new projects in intermediate products, or risk having well-positioned global (Asia-Pacific) and regional (Canada) peers continue to secure the majority share of new capacity. And the U.S. must create an environment where its startup companies involved in next-generation active materials and other intermediate products—predisposed to building U.S. footprints—develop the necessary know-how and cost positions to become globally competitive in the long run.

Figure 5 U.S. structural disadvantages and learning curve challenges

[1] Due to the difficulties and costs associated with shipping these finished goods (i.e., size, weight, safety regulations)
[2] Exception: some active materials may localize owing to short shelf life and/or difficulty transporting, e.g., electrolytes
[3] Li-Bridge topic committee analysis

CHALLENGE: A lack of U.S. R&D- and pilot-scale line capacity for the commercialization of new technology

Taking new battery technology from the lab to industrial-scale production is characterized by both high cost and high risk. Companies seeking to commercialize new technology incur significant costs (e.g., materials, labor, equipment) to produce a range of prototype samples for testing and validation. Yet, there is no guarantee these companies will be able to recoup these costs if the new technology fails to meet requirements or attract enough customers. This perilous journey is often referred to as the “valley of death” because many programs and startups run out of funds and “die” before reaching commercialization and generating positive cash flow.

To de-risk the journey from the R&D lab to industrial-scale production and to manage expenditures, companies will often produce, test, and validate a new technology in several steps of incremental volume (and investment) rather than jump straight to industrial-scale production. The typical steps of producing incremental volume can be organized into three broad categories: lab-scale, pilot-scale, and industrial-scale. **Figure 6** provides details about each step.

Figure 6 By 2030, workforce demand will outstrip the existing workforce

Scale of production	Approximate annualized capacity[2]	Objective	Relative costs	Production line characteristics	US examples
R&D-scale	<1 MWh/yr (<200 cells/wk[1])	Developing and testing new materials, products, equipment, etc.	Capex: Low Per cell: High	Highly manual, highly flexible	Argonne National Lab; University of Michigan Battery Lab; Battery Innovation Center
Pilot-scale	1 - 500 MWh/yr	Evaluating and optimizing product manufacturability and process parameters; Producing significant quantities of product for qualifications testing	Capex: Moderate Per cell: Moderate	Partially automated, moderately flexible	Private: GM, Ford, Tesla Shared: Currently *none* (Future: New Energy NY)
Industrial-scale	>1 GWh/yr (>10 GWh/yr for EVs)	Maximizing output of quality product at lowest cost	Capex: High Per cell: Low	Fully automated, inflexible	Tesla/Panasonic; LG

1. Assumes 100 Wh per cell 2. Ranges are highly approximate. Actual capacities overlap across scales.

Options for small and medium sized businesses (SMEs): While large firms often have their own in-house pilot lines, SMEs typically cannot spend their limited funds to build and operate their own pilot line. Thus, SMEs secure third party-controlled pilot line capacity to meet their testing and validation needs. SMEs generally have two options for accessing an external pilot line:

- Partner with a large firm to gain access to the partner's dedicated pilot line
- Use a shared pilot line facility

Although using an external pilot line can help SMEs from a cost standpoint by eliminating the needed capex for an in-house pilot line, it is not without tradeoffs. There is no guarantee that the SME can find an interested partner and reach agreeable terms. SMEs are constrained by the capabilities and flexibility of the external pilot line, and SMEs risk exposing sensitive intellectual property whenever using shared facilities.

Availability of shared R&D-scale and pilot-scale production facilities: Li-Bridge participants report a shortage of shared pre-industrial-scale production facilities in the U.S. at both the R&D-scale (<1 MWh/year) and pilot-scale (1-500 MWh/year) production capacity ranges. This shortage extends product development and qualification timelines for producers at every step of the supply chain, but especially for companies seeking to commercialize raw materials, active materials, inactive components, and processing equipment.

At R&D-scale, numerous shared facilities exist in the U.S., but demand exceeds supply. Industry reports wait times to access an R&D-scale line in the U.S. average 12+ months (6+ months to find and select a suitable R&D-scale line and 6+ months before the first opening on a shared facility's schedule). [4] In contrast, in China and the European Union, Li-Bridge participants report it takes an average of one month to select a R&D-scale line facility and secure a booking—and subsequent builds and testing can be run continuously without additional lead time. At pilot-scale, industry reports, there are currently no shared pilot-scale facilities in the U.S. In contrast, Europe has developed a robust ecosystem of shared pilot-scale production lines (LiPLANET) with capacities of up to 150 MWh per year (CustomCells).

What's at stake: Limited capacity of shared pre-industrial-scale production lines (<500 MWh/year) in the U.S. slows the commercialization of new innovations and causes companies to look abroad to develop and commercialize next-generation products. Key implications include:

- **Reduced commercial value of innovation:** longer lead times to access shared R&D-scale and pilot-scale lines extends the time-to-market for new technologies and increases the risk that competition can catch up or innovate faster
- **Missed opportunity to innovate, build know-how, and develop the workforce:**
  - Pilot production facilities enable innovations in manufacturing processes and equipment as well as battery technology and materials
  - Pilot production generates crucial know-how related to product development and manufacturing processes and equipment that directly benefits firms when designing and ramping up their industrial-scale production
  - Shared pilot lines serve an important role in training and upskilling workers as well as testing new equipment
- **Flight of innovation and IP leakage overseas:** Li-Bridge participants report that some firms are choosing to perform their R&D-scale and pilot-scale production runs outside the U.S. for faster results, which exposes U.S.-generated intellectual property and builds specialized know-how overseas
- **Reduced competition:** Lack of shared R&D-scale and pilot-scale line capacity most hurts SMEs and creates a business environment that favors large incumbents who can afford in-house pilot line

[4] Estimates from Li-Bridge participants

CHALLENGE: A lack of domestic technical know-how, especially in midstream activities

A highly skilled workforce sits at the heart of the U.S. battery sector's ambition to be self-sufficient and globally attractive. The U.S. has a strong foundation in battery materials and cell design, research, and development thanks in part to DoE labs, world-class universities, and innovative entrepreneurs and startups. Yet, the U.S. lithium-based battery industry currently lacks the depth and breadth of expertise in large-scale production required to build and sustain a secure, globally competitive industry.

Extent and quality of know-how: Today, the U.S. workforce does not have the same experience in lithium-based battery manufacturing as other countries, such as China. The at-scale manufacturing footprint in the U.S. is largely just starting to take root, with cell manufacturing leading the way relative to other parts of the supply chain. Still, the cell manufacturing in the U.S. today is often heavily supported by workers on visas or visiting experts from overseas. Years on plant floors, accumulated by long-term U.S. workers, are needed to develop the capabilities necessary to build cost-competitive batteries.

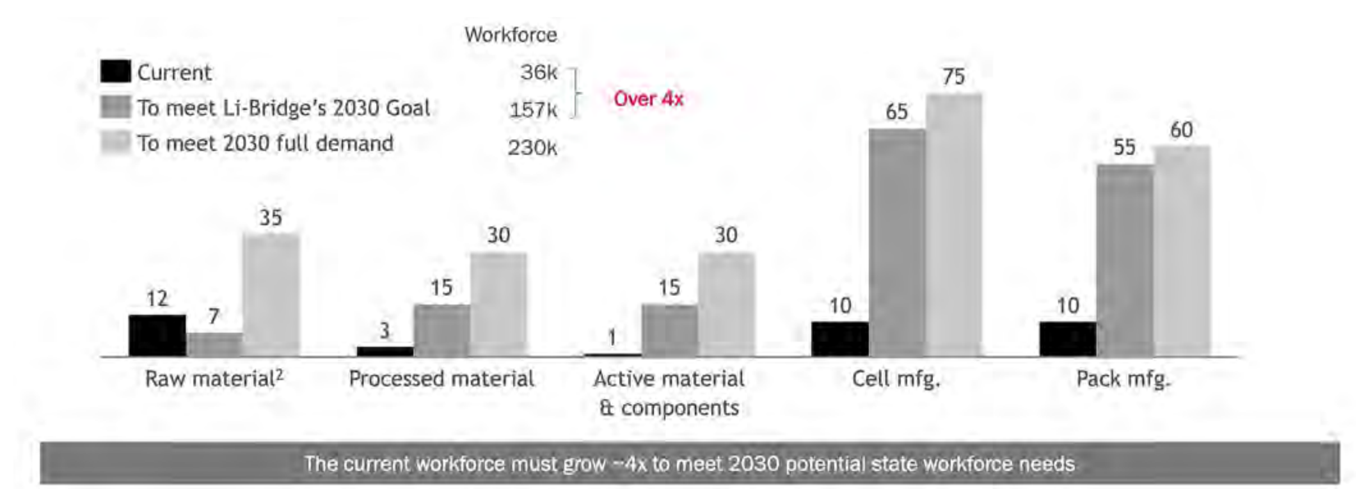
Manufacturing know-how consists of knowledge about procedures and methods of production. Transferring know-how is difficult for three reasons: (1) it is often tacit rather than explicit knowledge; (2) much of it is specific to the plant, equipment, suppliers, materials, and processes used; and (3) companies are highly protective of sharing it. Thus, acquiring large-scale manufacturing know-how requires direct experience.

Expertise in large-scale production is needed across the entire battery supply chain, though midstream segments face the most acute need. Within these segments, the following types of functional roles are most needed:

- Design and optimization of large-scale production operations—e.g., process engineers, industrial engineers
- Research and development of battery materials and cell designs—e.g., electrochemist, material scientist
- Supervision and operation of large-scale production operations—e.g., skilled workers

Future workforce gap (quantity): Achieving Li-Bridge's 2030 Goal for U.S. partial self-supply will require over 120,000 additional workers across the battery supply chain.[5] Headcount must grow by more than four times today's workforce—with more needed in adjacent and supporting segments such as used battery collection, maintenance and repair, end product integration, charging infrastructure, first response, and fire and rescue.

Figure 7 By 2030 workforce demand will far outstrip the existing workforce



1. Current workforce estimated multiplying US production numbers against 2022 jobs/GWh requirement and adding workforce top battery mfg. startups 2. Mining current workforce figure includes production for non-battery applications Source: Li-Bridge-BCG demand model, Li-Bridge experts, industry benchmarks

[5] Includes raw material through pack mfg.; 157K needed for 2030 potential state vs 36K in 2022

Closing the workforce gap will require expanding the pipeline to educate and train workers at all levels and from all sources. Four sources of labor are available to close the workforce gap:

1. **Workers from similar sectors with a different technology focus**: e.g., materials mining and refining, chemical processing, and battery manufacturing.
2. **Workers displaced from fossil fuel dependent industries**: e.g., internal combustion engine manufacturing, oil extraction and refining, and coal mining. Reskilling these displaced workers could cover up to ~30% of the workforce gap in 2030 (considering headcount only, not skills or degrees).[6]
3. **New graduates**: e.g., students or apprentices from North American universities, community colleges, and trade schools.
4. **International talent**: e.g., experienced workers or recent graduates from overseas.

However, three challenges complicate the battery industry's ability to recruit and train:

1. The U.S. lacks nationally recognized curricula or accredited training standards and certifications to offer a clear path for these next waves of prospective workers.
2. Battery manufacturing must compete for talent among other growing sectors, e.g., the manufacture and installation of wind turbines and solar farms.
3. There is a geographic mismatch between emerging battery-related jobs and where fossil fuel industry workers are located today.

What's at stake: The U.S. battery industry's limited know-how, particularly in large-scale manufacturing, translates into delays and increased costs for U.S. producers:

- Companies take longer to find and develop new talent and must pay more.
- Plants take a longer time to launch production owing to higher levels of trial and error.
- Plants operate with lower productivity, higher scrap rates, and increased risk of production, and market quality issues.

U.S. competitiveness on cost, quality, and innovation hangs in the balance. So, too, do towns across the U.S. A cell manufacturing facility, for example, employs over 5,000 workers directly and thousands of others indirectly in the region. These jobs contribute to the vitality of the local economy and generate taxes for decades. Highly skilled jobs not filled in the U.S. because of lack of availability or quality are also likely ones that go overseas. An inability to provide well-paying incomes to workers displaced by the clean energy transition also carries the risk that the transition will be delayed or more expensive to execute.

[6] Assumes ~40K displaced workers from fossil fuel dependent industries

CHALLENGE: Limited suitable sites served by reliable, cost competitive clean energy

Manufacturers put a lot of thought into choosing where to build new capacity. Many factors are considered during the site selection process that either directly or indirectly affect the business case—e.g., proximity to customers and suppliers, energy costs, transport infrastructure, availability of clean energy supply, local labor availability, and access to innovation and education hubs. While the U.S. has an abundance of inexpensive land for industrial use, the number of sites ideally suited to meeting the battery sector's evolving requirements is rather limited today.

Limited sites served by steady, cost competitive clean energy: The greatest constraint from a site infrastructure perspective is the lack of access to a steady, cost-competitive clean energy supply. Materials processing and active material production are highly energy intensive activities, and materials producers are increasingly seeking sites supplied by clean energy sources to meet their own corporate decarbonization goals. corporate decarbonization goals" insert the words "and customer requirements. Firms require highly reliable energy supply, making hydropower more attractive than variable renewable energy sources such as wind or solar.

The U.S. continues to invest in renewable energy generation projects. Still, these also need to line up with the ideal location (access to customers, supply chains, and workforce) and operating timelines of battery manufacturers. Industry participants report a growing preference for sites directly supplied by clean power sources instead of relying on renewable energy credits from purchase power agreements. Long interconnection queues are only getting longer.

The European Union's proposed Battery Regulation–which would require producers to disclose their carbon footprint starting in 2024 and comply with a carbon emissions limit starting in 2027–is expected to further drive global battery material and cell makers to seek out clean energy sources when choosing locations for future capacity investments.

What's at stake: Value add from material processing and the production of active materials and separators represent over half of a cell's value. The U.S. risks being passed over for other countries with higher shares of stable, low-cost clean energy, such as Canada.

Canada, with its high share of existing clean power (>80% hydropower or nuclear in both Quebec and Ontario), is advantaged versus many parts of the U.S. Evidence of midstream producers' desire for low-cost, clean energy can be observed from the recent number of battery material and cell plant announcements in Eastern Canada: cathode active material plants in Quebec by POSCO Chemical and BASF; a cathode active material facility by Umicore in Ontario; and an LG Energy Solutions battery cell plant in Ontario.

CHALLENGE: A lack of domestic suppliers of key equipment and a reliance on protective, overbooked foreign suppliers

Many steps of the lithium battery supply chain require sophisticated equipment to economically produce quality materials and cells at high volume. Equipment design and manufacturing are also highly intertwined with the process and product innovation. Thus, securing reliable, timely access to cutting-edge equipment is important to building a robust and innovative lithium battery supply chain.

Global equipment manufacturing availability: Industry participants report that battery manufacturing equipment suppliers are currently overbooked, causing significant delays for critical equipment. For example, Li-Bridge participants cite 18-month lead times for electrode coating machines from Asia. By design or otherwise, manufacturers in Asia do not seem to suffer from the same delays

Access to next-generation equipment: Most of the global capacity for lithium battery cell specific manufacturing equipment is concentrated in China, Japan, and Korea. Sample leading companies include Wuxi Lead (CN), Yinghe (CN), PNT (Korea), and Hirano Tecseed (JP).[7] While the U.S. has domestic manufacturing capacity for general-purpose industrial manufacturing equipment such as material handling equipment, the U.S. possesses very few domestic suppliers of equipment unique to lithium battery cell manufacturing.

Even when demand for equipment does not outstrip supply, Li-Bridge participants report that cell manufacturing equipment suppliers typically prioritize their home markets and local partners in Asia first. Sales of latest-generation equipment to international markets are often multiple financial quarters later. Equipment suppliers are also highly protective of their intellectual property and know-how. Exports are common versus establishing international production locations. Protectionist policies also include placing restrictions on where equipment engineers can travel and what levels of support are provided during setup and tuning, especially to newer customers.

What's at stake: A lack of equipment production in North America is a continuous disadvantage for U.S. companies seeking to produce competitive cells and cell components locally. Establishing secure, prioritized access to cutting-edge equipment for U.S. producers (a) addresses a supply bottleneck that could delay the U.S. and global battery scale-up and (b) reduces the risk that U.S. producers are deprioritized based on their origin of operations. If secure, prioritized access to cutting-edge equipment is achieved through a localized equipment supply, then the U.S. accrues the additional benefits:

- Increased value capture—estimated $60 billion in cumulative U.S. capital spending for equipment through 2030[8]
- Increased domestic equipment know-how, which would help U.S. cell makers optimally select and operate equipment (leading to higher yields and shorter ramp-up periods) as well as generate and test bottom-up manufacturing process innovations

[7] Morgan Stanley, "Lithium Battery Equipment – Seeking Alpha Through Cycles", June 2022
[8] Equipment needs to meet 2030 target, includes raw material through cell manufacturing; assumes 60% of capex is for equipment. Battery Atlas 2022, Heiner Heimes, (PDF) Battery Atlas 2022 Shaping the European lithium-ion battery industry (researchgate.net)

A.2. Parallel objectives

Altogether, the above recommended initiatives advance several objectives in parallel:

- Security (supply chain robustness and resiliency)
- Sustainability (e.g., decarbonization, environmental protection, recycling)
- Equity (place-based, environmental, social, and economic)
- Long-term economic competitiveness

A. Security (supply chain robustness and resiliency)

As the primary objective of the Li-Bridge project, Li-Bridge's recommended initiatives support creating a secure U.S. lithium battery supply chain in a multitude of ways:

- By supporting domestic production and recycling through incentives, investment, and regulatory changes
- By diversifying sources of supply through foreign partnerships and investments
- By innovating to create substitutes and reduce demand for critical materials

Going forward, the Li-Bridge alliance must continue to monitor the U.S. lithium battery supply chain for vulnerabilities and provide guidance to the U.S. government on how it can ensure U.S. economic and national security. Li-Bridge should also continue to seek out opportunities to leverage and cooperate with related domestic and international organizations including but not limited to:

- Bilateral partnerships with foreign governments and association with the private sector alliances, e.g., Canada or European Battery Alliance (EBA)
- Intergovernmental organizations, e.g., International Renewable Energy Agency (IRENA)
- Multi-lateral initiatives, e.g., Minerals Security Partnership (MSP)

Figure 8 Recommended initiatives advance multiple objectives

	Objective			
Recommended Initiative	**Security**	**Sustainability**	**Equity**	**Economic competitiveness**
1.1. Capex incentives	✓	✓	✓	○
1.2. Production incentives	✓	✓	✓	○
1.3. R&D incentives	✓	✓	✓	✓
1.4. Demand incentives	✓	✓	✓	✓
1.5. Government procurement	✓	○	○	✓
1.6. Insurance pools	✓	○	○	✓
2.1. R&D investment	✓	✓	○	✓
2.2. Pre-commercial scale lines	○	○	○	✓
2.3. Standards	○	○	○	✓
2.4. Commercialization support	✓	○	○	✓
3.1. Permitting reform	✓	○	○	✓
3.2. Critical minerals database	✓	○	✓	○
3.3. Buying consortium	✓	○	○	✓
3.4. Foreign partnerships	✓	○	○	✓
3.5. Circularity	✓	✓	○	○
3.6. Trade control	○	○	○	✓
3.7. Critical minerals sea mining	✓	○	○	✓
3.8. Stockpile	✓	○	○	✓
4.5. Infrastructure	✓	✓	○	✓
4.6. Industrial zones	✓	○	○	✓
4.7. Community engagement	✓	○	✓	○
4.1. Curricula development	✓	○	○	○
4.2. Curricula deployment	✓	○	✓	○
4.3. Training support	✓	○	✓	✓
4.4. Technical exchange	✓	○	○	○
5.1. Public-private alliance	*Enabler*			

B. Sustainability (e.g., decarbonization, environmental protection, recycling)

The Li-Bridge alliance recognizes the importance of creating an environmentally sustainable lithium battery supply chain. The recommended initiatives promote sustainability in several ways:

- By promoting low carbon production
- By supporting R&D for more environmentally benign and lower-carbon-emitting processes
- By supporting recycling and circularity
- By supporting the generation of reliable clean electricity

Areas of support: In addition to aligning on the above recommended initiatives, Li-Bridge participants support the following statements:

- **Commitment:** Industry is committed to (a) decarbonizing in line with the stated U.S. goal of net-zero by 2050 and (b) developing, operating, and shutting down operations in an environmentally benign manner that is consistent with government regulations.
- **Financial obligations:** While meeting sustainability goals, companies must also continue to meet the financial expectations of investors and the cost expectations of customers.
- **Differentiation:** Companies want to compete on sustainability and emissions and view it as a competitive edge.
- **Capital conditions:** Access to government capital should be, in part, dependent upon performance against simple, clear environmental metrics (with performance assessed on a sliding scale, not a binary threshold).
- **Electricity:** Industry desires industrial zones served by electricity generated from clean energy sources, especially for mid- and downstream operations; some industry members strongly prefer to know their facilities are powered by 100% clean energy rather than purchase renewable energy credits on a mixed grid.
- **Circularity:** Industry supports the creation of a world-class domestic circular economy through a combination of laws, standards, and incentives.
- **R&D:** Industry supports R&D investment in clean, low-emission processes and materials.
- **Accelerated permitting:** While the industry is clear that permitting in the U.S. must be accelerated to enable the U.S. clean energy transition, the industry does not request for lowering U.S. environmental standards.

Areas of hesitancy: In contrast, Li-Bridge participants express hesitancy or mixed views on the following issues:

- **Bans:** Industry is generally unsupportive of bans, e.g.,
  - On producing and selling ICE vehicles
  - On importing materials from countries of concern, e.g., DRC
  - On sea-based mining (seabed or seawater)
- **Recycled content:** Industry generally does not support recycled content quotas given the unpredictable demand and supply cycles inherent in a fast-growing sector
- **Fossil-fuel-free mining:** Industry believes it is too early to require 100% fossil-fuel-free mining and it is unclear whether decarbonization targets for the mining sector should be slower (or can be faster) than the economy-wide net-zero pathway.
- **Carbon pricing:** Industry is open to the concept of carbon pricing, such as Europe's carbon border adjustment mechanism, but recognizes its implications extend far beyond the battery industry.
- **Transparency:** While the industry supports sharing certain information, such as material provenance, the industry expresses concern that incremental cost of compliance may deter customers and slow energy storage adoption.

C. Equity (place-based, environmental, social, and economic)

The Li-Bridge alliance recognizes the importance of promoting equity in its many forms. In addition to recommending initiatives that include enhanced community engagement and workforce development efforts, the Li-Bridge alliance agrees with the following statements:

- Companies must engage early and often with local communities to understand their concerns and ensure that projects benefit to the local community while minimizing negative externalities.
- Reskilling workers from declining fossil-fuel-based industries or identified communities should be prioritized for staffing the battery industry's workforce needs.
- Hiring U.S. workers should be prioritized before extending visas to foreign nationals, where those skills exist or can be learned quickly.
- Perfect must not be the enemy of good. The costs and benefits of building a strong lithium battery supply chain should be shared across all groups in aggregate, though some projects may promote equity more than others.

D. Long-term economic competitiveness

Cultivating competitive advantage is critical for U.S. industry to compete globally and reduce future need for government subsidies and/or policy intervention.

The industry believes that with sufficient scale and time, U.S. firms can gain sufficient know-how to narrow the landed cost gap relative to other countries. However, to build sustainable competitive advantage and overcome the US's higher costs and lack of critical mineral resources, the industry believes the U.S. must lean into *innovation* and *speed to market*.

Li-Bridge's recommended initiatives support building sustainable competitive advantage for the U.S. in innovation and speed to market in several ways:

- By jumpstarting U.S. capacity investment to gain know-how in high volume manufacturing.
- By investing in R&D for innovative materials, technologies, and processes.
- By supporting shared pre-commercial production lines and commercialization support to bring U.S. innovations to market more quickly.
- By investing in workforce development to ramp up production more quickly and drive continuous improvement.

Innovation must occur in all forms (product, process, and business model), at all levels (breakthrough innovation and continuous improvement), and across all segments (upstream to downstream) to ensure enduring demand for US-produced products. To achieve this vision of innovating in all areas, the U.S. must build upon its solid foundation in materials innovation today and develop strengths in new areas, such as manufacturing processes and equipment.

In building an innovation and commercialization eco-system, the U.S. should leverage and build upon existing government efforts, such as the Department of Energy National Labs, Advanced Research Projects Agency – Energy (ARPA-E), and Manufacturing USA.

By investing in R&D, commercialization support, and workforce development, the U.S. industry can build a sustainable engine of innovation that keeps U.S.-produced batteries at the cutting edge and ensures continued demand without government support.

A.3. Recent developments (*additional details*)

The Biden-Harris administration recently published the National Security Strategy in October 2022, which states "strategic public investment is the backbone of a strong industrial and innovation base in the 21st century global economy". The recommendations in this whitepaper are grounded in the policy, regulatory, and legal frameworks outlined in the Strategy and established through recent legislative and executive actions.

The past year has witnessed many developments with implications for the U.S. lithium battery supply chain. Two U.S. laws are most significant among these developments: the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022.

- Infrastructure Investment and Jobs Act of 2021 (IIJA), aka Bipartisan Infrastructure Law (CRS) (DOE FOA)
  - Signed into law in November 2021. Authorized $1.2 trillion, of which $550 billion was new spending for infrastructure improvements, e.g., highways, power, and water.
  - Appropriated ~$76 billion over five years for energy and minerals-related research, demonstration, technology deployment and incentives, mostly through the U.S. Department of Energy (DOE), including $7.9 billion for battery manufacturing, recycling, and critical minerals.
  - In February 2022, the DOE issued two funding opportunity announcements (FOA) totaling ~$3 billion to boost the production of advanced batteries and components in the U.S. using funds appropriated to the DOE from the IIJA.
- Inflation Reduction Act of 2022 (IRA)
  - Signed into law August 2022. Raises $737 billion in revenue through tax collection and deficit reduction, invests $369 billion in energy security and climate change measures, and $64 billion in extending the Affordable Care Act.
  - Included among the energy security and climate change measures are significant investments for both the supply and demand sides of the domestic lithium battery supply chain.

Figure 9 summarizes the two laws' key provisions affecting the U.S. lithium battery supply chain and where they overlap with Li-Bridge's recommendations. Together, the IIJA and IRA direct significant government funding and action toward strengthening the U.S. lithium battery supply chain. The industry is strongly encouraged by these actions. However, the IIJA and IRA do not fully address the industry's key challenges, and much work remains to be done.

Figure 9 IIJA & IRA provisions provide significant support for improving U.S. investment attractiveness and infrastructure, but gaps remain elsewhere

Law & category of provisions	Selected key provisions	attractive-ness	and innovation	material, infra	People / Workforce	private alliance
IIJA (BIL)						
Investments in the domestic battery supply chain and supporting research	Multiple grant programs to support battery material and component manufacturing and recycling (totaling >$7B); scope covers R&D, demonstration, and commercial deployment	✓	✓	○	○	○
Investments in mapping/data collection for critical minerals	Several provisions fund USGS efforts to accelerate mapping and data collection of mineral resources, support mineral provenance tracking, and support energy and minerals research	○	○	✓	○	○
Investments in infrastructure	Significant funding appropriated to US infrastructure broadly, including power and grid, roads, rail, and ports	○	○	○	✓	○
Calls for future work	• DOE directed to study energy storage system codes and standards for greater collaboration and conformity across sectors • BLM and FS directed to establish schedules for federal permitting and review processes related to critical mineral mines on federal lands • DOE directed to assemble an energy workforce advisory board	○	✓	○	✓	○
IRA						
Investments in the domestic battery supply chain	• Extension of investment tax credit for projects that reequip, expand, or establish qualifying advanced energy projects (includes battery materials and components, among other) (CBO estimates $10B through 2031) • New production tax credit for domestic production and sale of qualifying materials and components (includes battery materials and components, among others) (CBO estimates $30B through 2031) • Multiple other funding provisions for expanding DOE LPO ATVM lending authority, domestic manufacturing conversion grants, and enhanced use of DPA	✓	○	○	○	○
Investments in clean transportation	Multiple credits, grants, and funds to support consumer purchase and government procurement of clean vehicles. Provisions include eligibility requirements, e.g., Sec. 13401 Clean Vehicle Credit includes requirements for sourcing of critical minerals and battery components.	✓	○	○	○	○
Investments in permitting process	Agency funding for efficient, accurate, and timely reviews for permitting/approval processes	○	○	✓	✓	○
Gap remaining (*Li-Bridge recommendation pillar not addressed by IIJA & IRA*)		◔	◕	◕	◑	●

BIL sources: R47034 (congress.gov); R47262 (congress.gov); H. R. 5376 (Enrolled-Bill) (congress.gov)

✓ Provision aligns with/overlaps Li-Bridge recommendations

Two additional recent U.S. federal government actions highlight other major components of modern industry strategy: the CHIPS and Science Act of 2022 ('CHIPS Act') and the Defense Production Act (DPA). The CHIPS Act is a clear demonstration of renewed industrial support at a sector level (in this case, semiconductors). The Defense Production Act (DPA) demonstrates how existing tools at the government's disposal can be applied to go further, faster. Combined with the IRA and IIJA, there now exists a strong and timely foundation against which solutions outlined in this whitepaper can be implemented.

A.4. Definition of key terms

Critical minerals: Per the Energy Act of 2020, a "critical mineral" is a non-fuel mineral or mineral material essential to the economic and national security of the U.S. and which has a supply chain vulnerable to disruption. The USGS applies a rigorous methodology to identify and evaluate potential critical minerals and periodically publishes an updated list of critical minerals. The USGS published the latest critical mineral list in Feb 2022, which included 50 mineral commodities.[9] Critical minerals include but are not limited to aluminum, cobalt, fluorspar, graphite, lithium, manganese, and nickel.

Energy materials: Used in this report to refer to any material used in the production of lithium batteries, including (a) critical minerals, (b) non-critical raw materials, (c) chemical intermediates, and (d) recycled materials/black mass.

Due to the complexities of refining and processing flow sheets, numerous additional intermediate materials and reagents used in the production of lithium batteries were not explicitly evaluated as part of the Li-Bridge initiative. These inputs include sulfuric acid, silane gas, hydrogen fluoride, sodium carbonate, and more. However, the absence of consideration of these inputs does not indicate Li-Bridge views these items as immune from potential future supply chain challenges.

9 U.S. Geological Survey Releases 2022 List of Critical Minerals | U.S. Geological Survey (usgs.gov)