NREL
Transforming ENERGY

2023 State of Innovation: **Emerging Climate Technologies Primed for Private Investment**

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Abstract

Over the last 100 years, global society has experienced profound advances in ways to produce, consume, and store energy. Energy systems today continue to undergo significant change to remodel the grid, sustainably support a growing population, and mitigate effects of global greenhouse gas emissions. The National Renewable Energy Laboratory (NREL),[1] dedicated to tackling the planet's most pressing energy and climate issues, has long been a cornerstone of American efforts to adopt a clean energy economy. NREL's technical leadership has helped to shape what follows here: a snapshot of technologies forging into the clean energy transition.

Mature renewables such as solar and wind energy have benefited greatly from earlier federal funding that enabled massive private-sector investments and deployment at scale, transforming global energy production. **Nascent and emerging energy technologies like carbon capture, geothermal energy, and industrial decarbonization can also be expected to attract sizeable private investment, but the question of when these technologies are ready for concentrated private sector and commercial activity remains.** NREL's Innovation and Entrepreneurship Center (IEC)[2] sits at the crossroads of public and private funding, working to bring economically viable cleantech innovations to market for global impact. The IEC vantage point provides the opportunity to evaluate the impact of public and private funding on emerging, nascent, and mature cleantech sectors.

In the first part, a broad analysis drawing from public agency (U.S. Department of Energy) and private funding data reveals the progression to private investment is faster today for technologies like geothermal and industrial decarbonization than it was for solar or wind. Many players drive this acceleration, including private investors, the federal government, and innovators and entrepreneurs. NREL and the IEC bring this ecosystem together, while catalyzing technology development and working closely with industry, investors, and startups. **NREL and IEC data from this ecosystem is used to identify cleantech and climate-tech sectors experiencing acceleration and growth and is shared in the second part.** At NREL's 2023 Industry Growth Forum (IGF),[3] a gathering of top cleantech investor and startup talent, characteristics and trends of this innovation ecosystem were presented and are now shared here as a 2023 state of cleantech innovation.

The data show the progression to private investment is faster today for technologies like geothermal and industrial decarbonization than it was for solar or wind.

1 www.nrel.gov.

2 www.nrel.gov/innovate.

3 www.nrelforum.com.

The National Renewable Energy Laboratory (NREL), dedicated to tackling the planet's most pressing energy and climate issues, has long been a cornerstone of American efforts to adopt a clean energy economy.

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Introduction

The global energy economy is experiencing profound changes, necessitated by the need for safe, reliable, clean, and sustainable energy. Increased energy demands from a growing population, a changing supply chain, and the need to decarbonize add additional layers of complexity. Renewables like solar and wind power now compete in the energy marketplace as the lowest-cost generation sources, cheaper than natural gas and coal by a factor of 1.5 to 3x,[4] and fulfill one piece of the clean energy transition. Yet a full transition to a decarbonized energy world will require renewable and carbon-free electricity, as well as innovation, to drive drastic greenhouse gas reductions across intermodal transportation, the built environment, industry, manufacturing, and more.

During the oil and gas shortages experienced in the 1970s, the Carter[5] Administration established the U.S. Department of Energy (DOE) and the Solar Energy Research Institute (now known as the National Renewable Energy Laboratory [NREL]) to develop alternative and renewable energy sources. Since then, a collaborative effort involving the DOE, NREL, and industry has unlocked a new paradigm for solar and wind technologies through achievements in technology performance and reliability and significant cost reductions across cell/turbine and system levels. With solar and wind now mature and low-cost, NREL continues to support research innovations and influence these sectors by shaping paths for optimized deployment. The Biden Administration is working to speed up decarbonization by setting a goal of net zero emissions by 2050, driving NREL to develop low-carbon technologies beyond simply electricity.

Effective new technology adoption into commercial markets requires coordination among many stakeholders, including the federal government, industry, private investors, and entrepreneurs. The federal government has invested a cumulative $15 billion[5] into NREL's campus that hosts one-of-a-kind labs, facilities, and testing capabilities paired with world-class research expertise. NREL creates technological breakthroughs in key areas like advanced manufacturing, bioenergy, buildings, energy security and resilience, geothermal, storage, hydrogen, solar, water, wind, and more. In 2022, NREL's expansion and growth[6] was reflected by an increased workforce of 3,200 staff, almost doubling since 2017. In that same year, NREL's funding volume of $671 million[7] reflected a growing need and urgency from DOE and private-sector industry partners to achieve net zero greenhouse gas emissions by 2050.

Recognizing that NREL sits at a nexus of public and private energy activity, the laboratory commissioned its Innovation and Entrepreneurship Center (IEC) in 2014 to bring economically viable cleantech innovations to market. The IEC makes this possible by serving private and public funding partners, providing them access to NREL's expertise and capabilities and activating and connecting a network of cleantech and climate-tech startups, investors, foundations, and industry partners. Its flagship event, the Industry Growth Forum (IGF), annually connects the private investment community with startups, catalyzing the investment needed to commercialize the full spectrum of climate technologies.

Motivated by this view, a presentation on the state of innovation was delivered at the 2023 IGF. This work captures elements from that presentation, as well as learnings and insights across nascent (technologies showing viability and promise), emerging (technologies ready for scaling), and mature (scaling or scaled technologies) innovation through analysis of DOE and private-sector investment reflected in the PitchBook database, the IEC startup portfolio, and NREL partnership data. This state of cleantech innovation enables investors, accelerators, incubators, and entrepreneurs to consider trends in emerging innovation as they allocate time and resources towards decarbonized energy solutions.

4 Lazard's 2021 Levelized Cost of Energy Analysis: https://www.lazard.com/media/sptlfats/lazards-levelized-cost-of-energy-version-150-vf.pdf.

5 https://www.nrel.gov/about/history.html.

6 https://www.nrel.gov/news/features/2022/nrel-delivers-impact-through-commercialization-in-record-volume-at-critical-time.html.

7 https://www.nrel.gov/about/.

Background and Methods

Part I: Cleantech and Climate-tech Public and Private Funding Trends

Data were collected from several sources to explore cleantech and climate-tech innovation in the United States at three distinct points (2015, 2018, and 2022), illustrating evolving funding trends. For the U.S. public sector, DOE funding was drawn from a dataset developed and maintained by Gallagher et al.[8]; this dataset captures total appropriated funding for each technology office at DOE (e.g., Solar Energy Technologies Office or the Wind Power Technologies Office) from year to year. Each technology office at DOE distributes annual appropriated funding to a variety of stakeholders, including industry, small businesses and startups, universities, nonprofits, and national labs. Other government agencies funding energy innovation (e.g., National Science Foundation, U.S. Department of Defense) are not tracked in this dataset.

For private funding in the United States, PitchBook[9] was used to gather information for distinct technology areas using keywords solar, wind, hydrogen, carbon capture, geothermal, and industrial decarbonization and electrification. For each keyword, the total amount of private investment (in U.S. dollars), total number of private deals, and number of *new* startups formed that particular year were collected. Total private investment is the combination of angel, grant, venture capital, mergers and acquisitions, and private equity invested into U.S.-based startups commercializing technologies in each keyword sector. PitchBook data are not exclusive to private investment, as the database also records grant funding acquired by startups; however, PitchBook can provide important insights into private investment activity.

For each year evaluated and each unique technology sector, DOE funding was compared to total private funding and leveled by the total number of private deals made that particular year (Figure 1 and Figure 2). A dimensionless ratio was calculated by dividing the total private funding by DOE funding and plotted with the total number of new startups formed in that year for each technology sector (Figure 3). A ratio greater than one indicates that technology is receiving more private funding than public funding (DOE).

Part II: NREL's Ecosystem of Industry Partners, Investors, and Startups

Internal NREL datasets provided by the laboratory's partnership team were used to share insights on NREL's industry partnerships (Table 2/Figure 5). NREL also gathers data on attending startups and investors year to year through IGF registration information (Figure 4 and Figure 5). Beyond the data gathered on startup investments via PitchBook, IEC continually adds startups to its portfolio with each new technology incubation cohort supported by Wells Fargo IN[2], Shell GameChanger Powered by NREL, and West Gate programs. As of May 2023, the IEC supports 84 companies across technology incubation programs, spanning buildings, grid, energy storage, fuels, chemicals, solar, industrial electrification, and more. For the IEC startup portfolio, metrics are collected for each startup over time to track previous funds raised and future raises, employee growth, revenue, mergers and acquisitions, technology readiness level, and partnerships. Because each program invites startups to apply, the IEC also maintains data on applying companies, even if they are not selected (Figure 6).

8 DOE Historical Funding: Gallagher, K.S. and L.D. Anadon, "DOE Budget Authority for Energy Research, Development, and Demonstration Database," Fletcher School of Law and Diplomacy, Tufts University; Department of Land Economy, University of Cambridge; and Belfer Center for Science and International Affairs, Harvard Kennedy School. April 8, 2022.

9 PitchBook Database. 2023. Data retrieval between January and June 2023.

Results and Discussion

Part I: Cleantech and Climate-tech Public and Private Funding Data

DOE's Role in Maturing Solar and Wind

The public sector has continually influenced innovation through direct investments in clean energy technologies—with DOE as a leading investor. Mazzucato's *The Entrepreneurial State*[10] elucidates many cases where public sector funding of high-risk, early-stage technology strongly influences downstream private sector investment and innovation activity carried out by industry, venture capital, and startups. Thus, the public sector sets the vision for nascent and emerging innovation, playing a formational role well before the private sector enters. Recognizing the public sector's role, recent funding data from DOE are captured and compared with private sector funding (angel, venture, mergers and acquisitions, and private equity) to identify cleantech sectors that are relatively still early (i.e., technology sectors in which DOE is the leading investor, relative to the private sector).

Figure 1 compares DOE funding to private investment in startups commercializing solar or wind innovations at distinct points (2015, 2018, and 2022). For both sectors, private funding greatly exceeds DOE funding, indicating investor confidence in wind and solar for generating returns. Equally noteworthy is the near tripling of deal count in both solar and wind from 2015 to 2022. Decades ago, DOE was the primary investor in solar well before the private sector. In 1999, the total investment into solar by DOE was $115 million,[7] almost 40 times more than the private funding in solar that same year, $3 million, which mainly comprised early-stage venture and

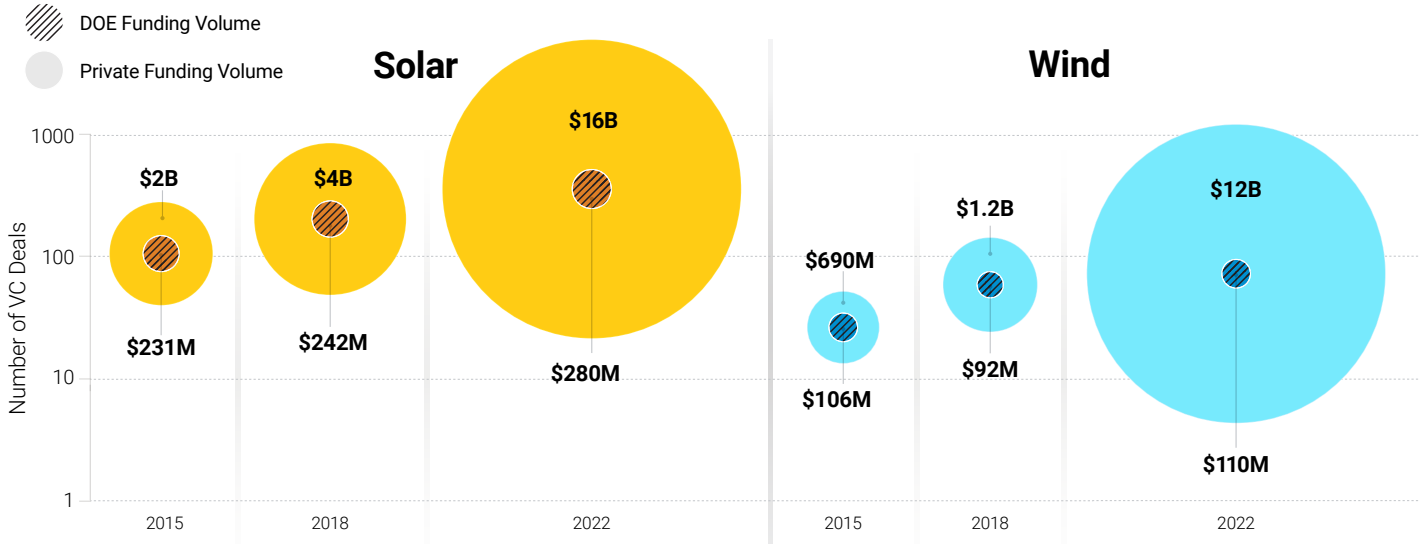

Figure 1. Solar and wind that were government-enabled and now private sector-led. Comparison of DOE funding volume, as authorized by Congress, to private funding for investment in solar and wind startups.

10 Mariana Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. 2015.

angel investing. This demonstrates that DOE was the leading early-stage investor supporting the fundamental research and development needed to unlock the high performance demanded by the market.

By 2015, private funding in solar was nearly an order of magnitude higher than public funding, and by 2022, it was 57-fold higher. The flip in funding dominance signifies DOE primed the sector for dealmaking and private investment. Solar (and wind) technologies can now be conceptually described as "government-enabled, private sector-led," meaning DOE funded initial mission innovation activity, but the private sector now leads scaling and deployment. The transition from one to the other involves DOE funding targeting de-risking, shaping, and creating technology road maps, working alongside private sector funding enabling risky, early-stage startups to take unique commercialization approaches. It is when the transition is in progress, as shown by parity between public and private funding volume, that DOE finds most value in engaging private investors and entrepreneurs as they break ground on transformational opportunities.

Even long after the transition to the private sector, the public sector's role endures in identifying and de-risking enabling features of a technology as it scales up into deployable systems or environments. DOE's investments in solar and wind are not finished, as they will continue to be a vital component of a fully decarbonized future; to that end, DOE's evolving focus largely aims for ways to accelerate the deployment of both solar and wind. Certainly, the Inflation Reduction Act will be a strong tailwind for increasing domestic manufacturing and deployment activity.

Emerging and Nascent Cleantech Sectors Experiencing Rapid Acceleration

Understanding when the transition from public to private funding leadership is occurring provides a strong signal that a particular technology is ready for entrepreneurial activity, investment, and dealmaking. Examining recent tallies of public and private funding, several technologies display a clear trend of private funding volumes increasing significantly relative to public funding volumes.

Figure 2 illustrates the same methodology undertaken in Figure 1, but for the nascent and emerging cleantech sectors of hydrogen, carbon capture, and geothermal. Noticeably, DOE funding for carbon capture dwarfed private funding in the sector in 2015. Just a few short years later in 2018, private funding overtook DOE funding by a fraction, spurring a transition from DOE as the lead investor to the private sector. Then, in 2022, private funding substantially exceeded the amount of DOE investment.

Similar trends can be observed for geothermal and hydrogen. To add additional specificity, demarcated regions for each sector in Figure 2, denote whether a particular year was primarily enabled by government backing or was private sector-led, as determined by the comparative sizes of funding volumes for each.

To compare government-enabled, private sector-led transitions across sectors, a unitless ratio of private funding divided by public funding was computed (Figure 3). Ratios greater than 1 indicate the private sector leads investment, and, conversely, ratios below 1 indicate public funding is leading; thus, the ratio of 1 indicates the threshold for sectors to experience a transition. In alignment with their status as mature renewables, one can clearly see solar and wind residing above the transition line for all years evaluated, along with their respective large pools of new startups formed each year.

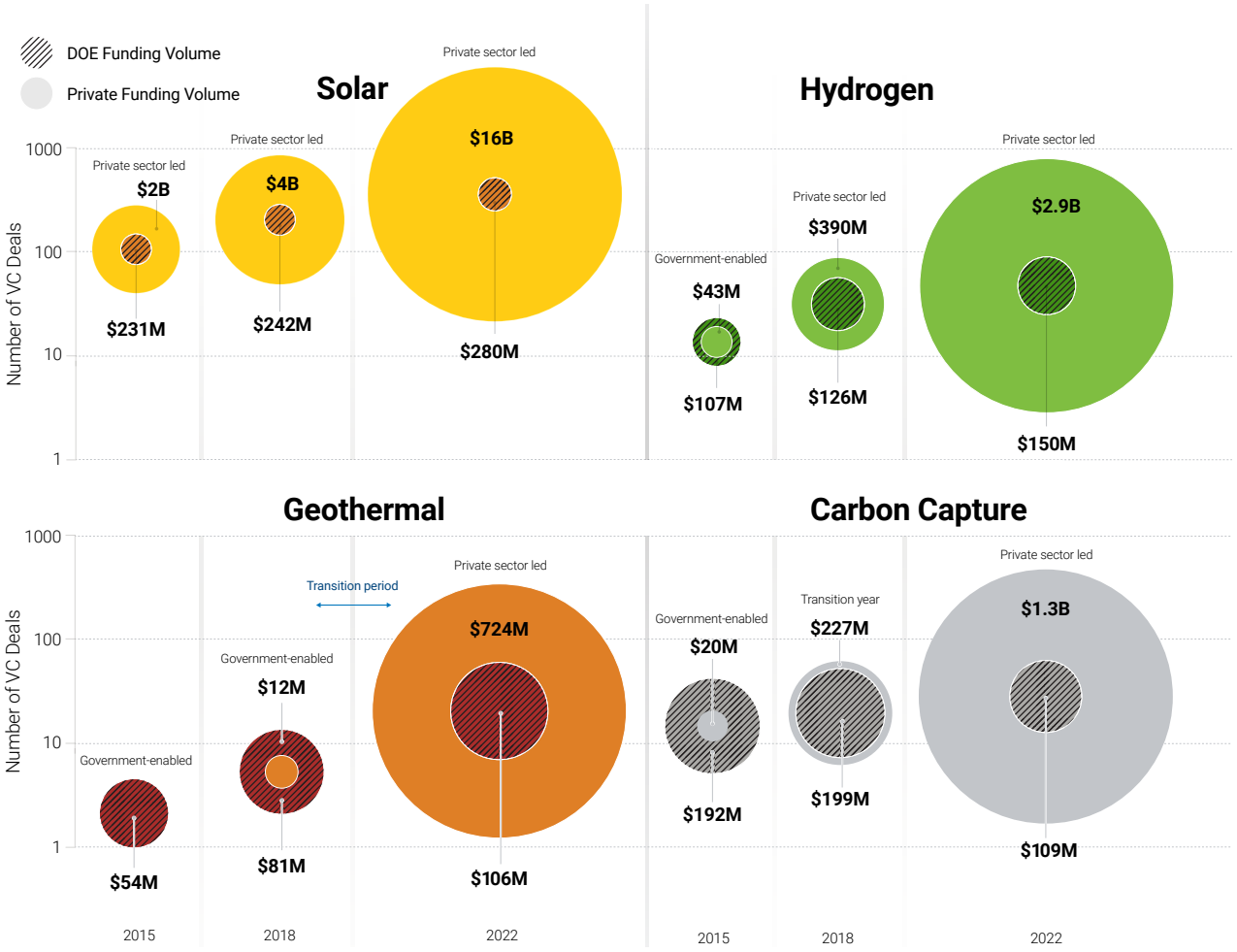

Figure 2. Nascent and emerging cleantech sectors beginning to experience government-enabled, private sector-led transitions. Circle sizes compare federal funding (DOE funding volume), as authorized by Congress, to private funding volume in solar, hydrogen, carbon capture, and geothermal startups.

What is clearly apparent in Figure 3 are the recent transitions experienced by hydrogen and carbon capture (2015 to 2018) and geothermal (2018 to 2022). DOE-funded research and development has laid fundamental groundwork leading investment to enable the private sector to come to the table in equal measure, having seen sufficient market opportunities. Geothermal technology funding has been transitioning in just the last few years leading into 2022. Each is now in a realm where private interest is gaining momentum and outpaces DOE funding.

Finally, as of 2022, industrial decarbonization was still primarily funded by DOE, qualifying as a nascent technology area where DOE is funding industry-relevant research and development (R&D) to create an investible market, and its transition to private sector-led is anticipated soon, if not already. Noteworthy, industrial decarbonization has approached the transition line at a faster rate than other analyzed sectors since 2015. Further fueling the acceleration, DOE recently established the Industrial Efficiency and Decarbonization Office with an inaugural annual budget of over $200 million.

Looking more closely at the acceleration, Table 1 ranks the sectors by rate of growth of private investment activity.

Industrial decarbonization has seen a 22,000x increase in private funding from 2015 to 2022, shown in Table 1. Industrial decarbonization and electrification is the sector most quickly garnering additional private investment, with geothermal in a second position. Unlike the solar and wind sectors, which have double- or triple-digit numbers of new startups formed each year, industrial decarbonization, geothermal, carbon

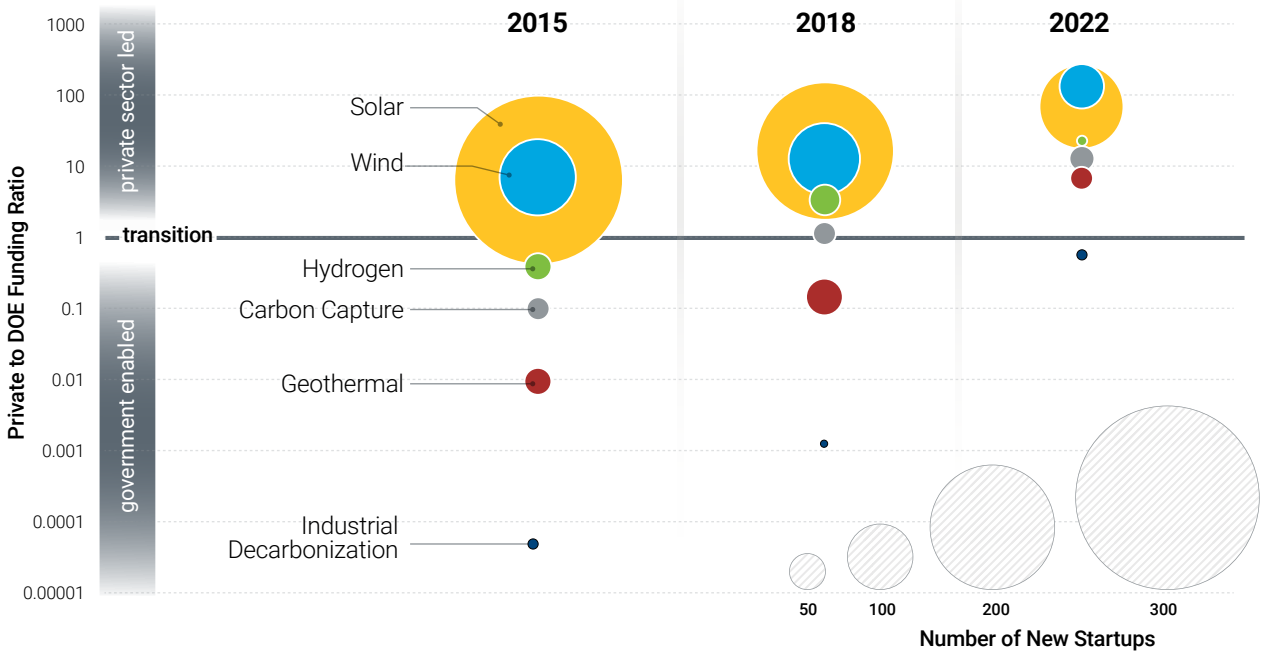

Figure 3. Government-enabled cleantech innovation readies for private sector entrance. Unitless ratios of DOE research, development, and demonstration funding volume to private investment funding volume into startups for various cleantech sectors since 2015. Circle sizes indicate the number of new startups formed that year.

Table 1. Cleantech Sectors Experiencing Most to Least Acceleration in Private Backing

	Rank	Technology Sector	**Approximate Transition Year** from DOE as Primary Funder to Private Sector	**Acceleration in Private Investment** (multiple from 2015 to 2022)	**Deal Count Increase** (multiple from 2015 to 2022)	**Number of New Startups** {2015, 2018, 2022}
Nascent/Emerging	1	Industrial Decarbonization	Anticipated after 2022	22,000x[a]	7x	{1, 0.5, 1}
	2	Geothermal	Between 2015 and 2018	>382x[b]	10.5x	{7, 13, 5}
	3	Carbon Capture	2018	68x	1.9x	{4, 5, 6}
	4	Hydrogen	Between 2015 and 2018	67x	3.5x	{7, 9, 1}
Mature	5	Wind	Before 2015	17x	2.8x	{56, 49, 19}
	6	Solar	Before 2015	6x	3.4x	{274, 182, 68}

a PitchBook recorded $10,000 in funding in 2015.

b PitchBook did not record any investment funding in 2015, but in 2016, $1.89 million was invested into geothermal; for computational purposes, the 2016 investment funding amount was utilized for 2015.

capture, and hydrogen have single-digit startups, indicating these technologies are nascent or emerging, with hydrogen leaning toward the latter. Such rapid acceleration of investment and limited magnitude of new startups year to year signals the opportunity for investors and entrepreneurs to invest early, akin to the very early days of angel and venture investing in solar and wind.

For each nascent and emerging cleantech sector presented above, it is worth noting a few characteristics of the market and technology as entrepreneurs and investors explore ground-floor opportunities.

Cement decarbonization presents a significant and sizeable opportunity to impact emissions broadly in the industrial decarbonization sector. Concrete is the second most-consumed material in the United States after water,[11] and 90% of the emissions created by the cement-making process result from the kiln where high-temperature combustion heat decomposes limestone into quicklime.[12] Innovators are currently pursuing ways to displace fossil-based heating with low-emissions fuels or electrified heating. Other strategies include finding alternatives to cement, like bio-based aggregates with lower carbon intensity.

Next in rank order, geothermal offers the opportunity to provide both heat and power continuously and with the smallest physical footprint[12] relative to other renewables. It is not surprising to see strong interest from the public and private sector for this technology. In 2021, the total installed geothermal power capacity in the United States was 3,672 MW,[13] and this is expected to grow, especially in states like California and Nevada. Geothermal has a strong role to play across many energy transitions. For example, it can be used to produce hydrogen (geothermal heat to electricity to power water electrolysis or reacting iron-rich rock with hot fluid to form hydrogen via serpentinization). Within the grid, it can generate power and couple to or firm other renewables. Geothermal reservoirs can be used directly for heat or to store thermal energy or CO_2 emissions. Other energy transition technologies like water desalination, critical mineral lithium extraction, and direct air capture can benefit from geothermal resources.

In third rank in Table 1, capturing carbon dioxide emissions resulting from human activity (carbon capture) is a considerable thrust of this sector. However, and beyond just capture, the community is shifting its view toward CO_2 being simply a waste stream to be managed in multiple ways via reduction, capture, utilization, and mitigation. First, decarbonization broadly focuses on ways to *reduce* waste CO_2 generated from human activities. Secondly, within decarbonization, managing emissions (past, present, or future) in ways that *mitigate* its effects are paramount. And finally, carbon dioxide removal (CDR) focuses on activities that capture or remove CO_2 from the atmosphere or oceans (marine CDR) and durably store or *utilize* it in geologic, terrestrial, or ocean reservoirs, or in products (fuels, chemicals, or materials made using CO_2 as a feedstock). A variety of CDR approaches exist, like direct air capture and storage, mineralization, biomass carbon removal and storage, land-based solutions (reforestation, afforestation), and ocean-based CDR (with a host of solutions like ocean alkalinity enhancement, upwelling, etc.). Overall, CDR is strongly nascent, with evolving technology development. Needs exist for robust monitoring, reporting, verification, life cycle analysis considering the durability and permanence of removal, innovative business models built around CO_2 credit frameworks, and appropriate verification of credits. All of this

11 Low, M., 2005, "Material flow analysis of concrete in the United States" Thesis, Massachusetts Institute of Technology, Dept. of Architecture: https://dspace.mit.edu/handle/1721.1/33030.

12 https://www.energy.gov/eere/iedo/cement-and-concrete-manufacturing#:~:text=Ninety%20percent%20of%20emissions%20from,clinker%E2%80%9D%20necessary%20in%20making%20cement.

13 2021 U.S. Geothermal Power Production and District Heating Market Report. NREL. https://www.nrel.gov/docs/fy21osti/78291.pdf.

leaves space for corporations, startups, academics, and research institutions to play a strong role in shaping this sector in the very early stages.

Hydrogen, wind, and solar have a wealth of reporting on innovation and investment tracking, and are bypassed in the discussion here. Instead, recognizing that rising cleantech sectors may not be uniquely siloed within one singular office at DOE, as with solar or wind (the Solar Energy Technologies Office and Wind Power Technologies Office, respectively), emerging cleantech innovations that commingle sectors are worth noting.

One case in point is sustainable aviation, a rising area of interest, with expressed demand from key stakeholders, airports, airlines, major oil companies, and consumers. Yet sustainable aviation requires multiple disciplines (and intra-office DOE collaboration) across bioenergy, renewables, fuels, manufacturing, grid integration, and more. Because of the increasing interest in sustainable aviation, DOE recently established a sustainable aviation grand challenge[14] to achieve 35 billion gallons of sustainable aviation fuel per year by 2050 (for reference, present-day production of conventional jet fuel in 2022 was 73 billion gallons[15]). Many challenges need to be solved to reach these scales, including reducing the variability of bio-feedstocks, matching conversion equipment to accommodate a variety of streams (waxes, oils, bio-oils/crude, sugars, algae oils, and lignin), and solving the mismatch between bio-based streams and conventional petroleum refineries. Lastly, sustainable aviation fuels that comply with recognized standards will become crucial for industry adoption. NREL is playing a convening role to solve some of these challenges through its deep and longstanding expertise and industrial partnerships in bioenergy and world-renowned capabilities in bio-based feedstock processing and characterization.

Sustainable aviation requires multiple disciplines (and intra-office DOE collaboration) across bioenergy, renewables, fuels, manufacturing, grid integration, and more.

As we shift toward widespread decarbonization, sectors like sustainable aviation needing "moonshot" support will require DOE's science and applied energy offices to work together to spur significant technological breakthroughs. Blurring between cleantech sectors will become more common in the approach to fully decarbonized energy systems and platforms by 2050. Recently, DOE launched seven Energy Earthshots™[16], each with tailored performance, emissions-reduction, or cost targets:

- **Hydrogen Shot:** reduce the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade ("1 1 1").
- **Long Duration Storage Shot:** reduce the cost of grid-scale energy storage by 90% for systems that deliver 10+ hours of duration within the decade.
- **Carbon Negative Shot:** innovation in carbon dioxide removal pathways that will capture carbon dioxide from the atmosphere and store it at gigaton scales for less than $100/net metric ton of carbon dioxide equivalent.
- **Enhanced Geothermal Shot:** dramatically reduce the cost of enhanced geothermal systems by 90%, to $45 per megawatt hour by 2035.

14 https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge.

15 https://www.statista.com/statistics/655057/fuel-consumption-of-airlines-worldwide/.

16 https://www.energy.gov/energy-earthshots-initiative.

- **Floating Offshore Wind Shot:** seeks to reduce the cost of floating offshore wind energy by more than 70%, to $45 per megawatt-hour by 2035 for deep water sites far from shore.
- **Industrial Heat Shot:** aims to develop cost-competitive industrial heat decarbonization technologies with at least 85% lower greenhouse gas emissions by 2035.
- **Clean Fuels & Products Shot:** decarbonizing the fuel and chemical industry through alternative sources of carbon to advance cost-effective technologies with a minimum of 85% lower GHG emissions by 2035.

In addition, DOE's Office of Technology Transitions (OTT) already works across the spectrum of DOE technical offices to accelerate clean energy technologies from lab to market. Their recent Pathways to Commercial Liftoff Reports[17] provide technical information to support government-enabled, private-sector-led transitions that are in progress or coming soon. Three of the Liftoff Reports align with the sectors identified here: Clean Hydrogen, Carbon Management, and Industrial Carbonization.[18] Each report is meant to be a living document that builds understanding around the technical maturity, pathway to market, and challenges facing each sector. The OTT also partnered with a leading information channel for clean energy investors, Climate Tech VC, to help disseminate this information to private funders.[19]

Part II: NREL's Ecosystem of Industry Partners, Investors, and Startups

Industry Partners Look to NREL to Accelerate Energy Transitions

DOE leverages 17 national labs as premier research, development, and demonstration centers, tackling large-scale scientific engineering challenges and building the scientific foundations of new innovation. NREL is the only national lab with a singular focus: to advance the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies, and provide the knowledge to integrate and optimize energy systems. Industry, corporations, and Fortune 500 companies look to NREL to advance critical energy solutions, with sizeable private R&D funding of $538 million spent at NREL for collaborative R&D in 2022 (this total funding amount does not reflect any direct DOE funding). Figure 4 summarizes where NREL partners spent their R&D dollars with NREL in 2022.

17 https://liftoff.energy.gov/.

18 https://www.energy.gov/lpo/pathways-commercial-liftoff-reports.

19 https://www.ctvc.co/3-2-1-doe-we-have-liftoff/.

Strong partner interest in the electricity generation, use, and management category (renewable electricity generation and grid integration, storage, advanced grid controls, etc.) stems from NREL's world-class expertise and one-of-a-kind testing capabilities in this space.

Strong market pull in the electricity generation, use, and management category (renewable electricity generation and grid integration, storage, advanced grid controls, etc.) stems from NREL's world-class expertise and one-of-a-kind testing capabilities in this space. NREL's unique Energy Systems Integration Facility[20] and Flatirons Campus[21] are capable of kW to MW hardware-in-the-loop testing, with 8 MW of installed wind and photovoltaic systems coupled with energy storage. Partners are also keen to work with NREL in nascent and emerging areas like the built environment, materials and industrial manufacturing, and climate management. With DOE's growing investment in nascent and emerging cleantech sectors, it is anticipated that NREL's partnership work in geothermal, carbon capture, and industrial decarbonization will also grow in some proportion.

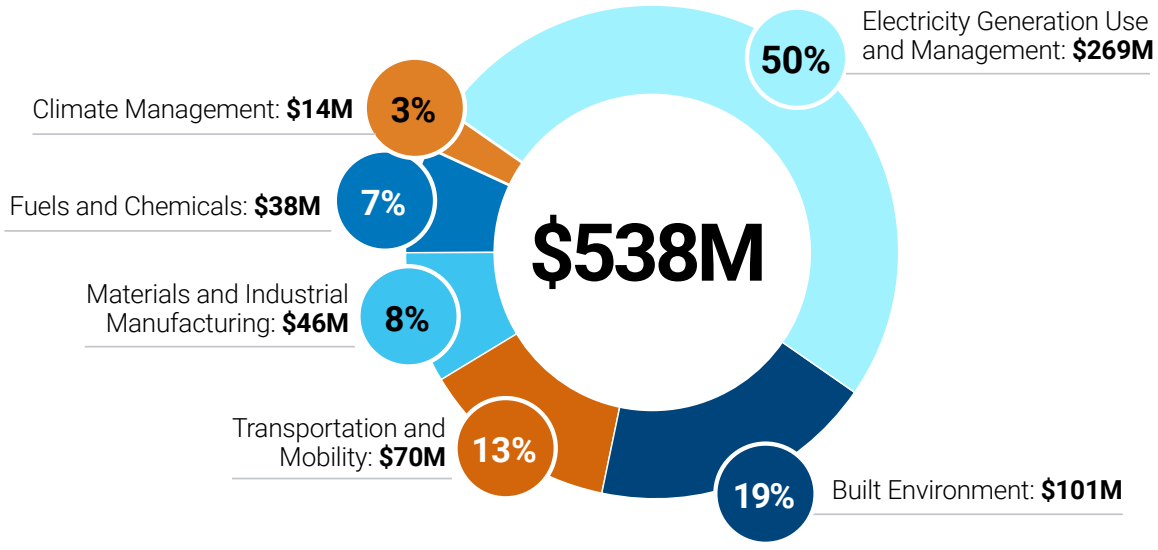

Figure 4. NREL Partnership Agreements With Industry (non-DOE Research, Development, and Demonstration) in 2022

20 https://www.nrel.gov/esif/.

21 https://www.nrel.gov/grid/grid-integration-nwtc.html#:~:text=Key%20Capabilities,variable%20generation%20on%20the%20grid.

NREL's Industry Growth Forum (IGF) Convenes Cleantech and Climate-tech Investors and Startups

NREL's IEC was commissioned to bridge investor and startup communities and move NREL R&D funded by both the DOE and industry partners toward market impact. Every spring, the IEC hosts the IGF and convenes over 700 clean technology specialists in a format that allows startups open access to private investors that move capital in support of clean technology solutions. At each Forum, thousands of facilitated meetings between investors and startups initiate transformational investments into those companies. As a group, startups that have presented on the IGF stage subsequently raised over $11.3 billion since 2003.[22] Launched in 1995, the IGF has been a long-running gathering for the cleantech ecosystem. Because of this, IGF has been witness to trends and changes in the technology types attracting startup commercialization efforts and respective investor interest.

The 2023 IGF had strong and unique representation, with 218 startups (279 startup attendees) and 163 private investment firms spanning corporate, family, and venture capital across pre-seed to series C and pre-IPO investments (232 investors attending). Approximately half of these attending investors reported a collective $16 billion (U.S. dollars) in assets under management (the remainder choosing not to report), with at least $3.3 billion targeted to invest within a year.

The IGF hosts startups commercializing a broad set of technologies across the entire cleantech and climate-tech umbrellas. Attendee registration data samples the cleantech innovation ecosystem year to year using the technology focus for each attending startup and interest expressed by attending investors. Figure 5 showcases a brief snapshot of this evolution represented by attending startups from 2020 to 2023.

The IGF has had a traditional focus on renewable electricity production technologies and continues to attract many startups working in the electricity and energy storage verticals. Solar photovoltaics, wind power, energy efficiency, grid technologies, integrated solutions across generation types,

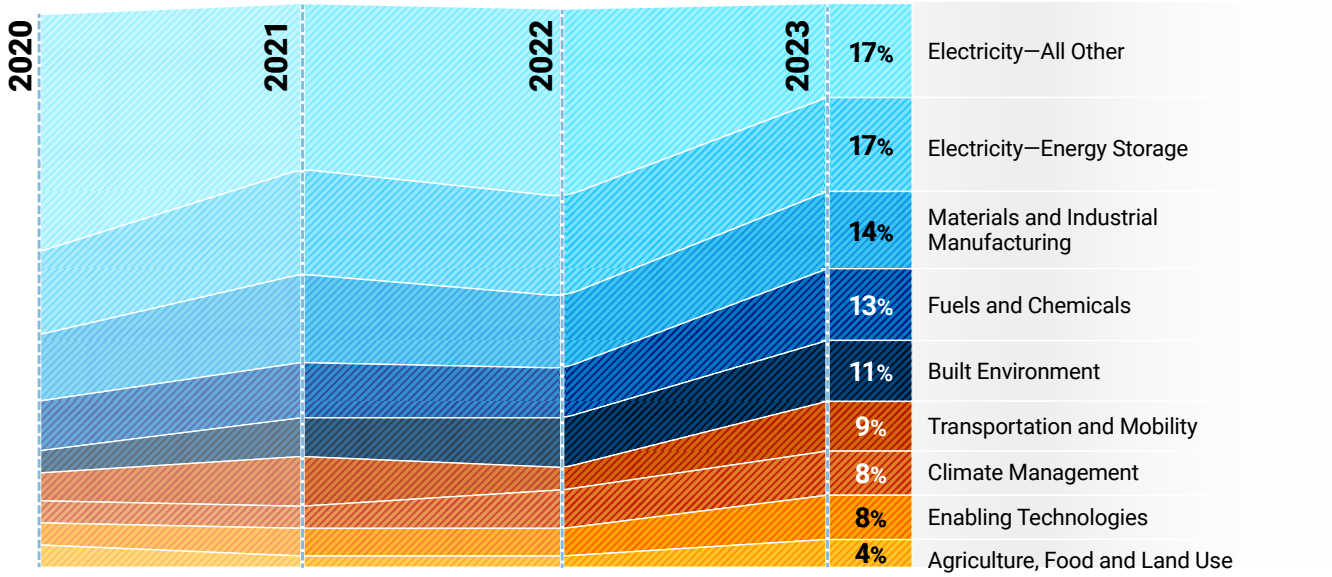

Figure 5. Recent history of IGF-attending startups across technology categories shows an increase in nascent and emerging technology sectors like climate management and industrial manufacturing.

22 PitchBook data on investments raised by all companies that have presented within the IGF pitch competition since 2003, since their appearance at IGF.

and more fall under the electricity vertical. Table 2 shows greater detail on the technologies with most startup representation.

While numbers of startups in electricity remain robust, relative decreases in the percentage of attending startups within the electricity vertical may point to key problems being solved and a relative maturing in the solar, wind, and energy management marketplaces. In 2022, solar photovoltaic electricity represented approximately 46% of new U.S. electric generation capacity, and in 2010, this figure was only 4%.[23] The need for innovation in the electricity sector (e.g., solar or wind) is coming into balance, with other sectors requiring substantial innovation to meet decarbonization goals. Electricity and energy storage remain stalwarts of the IGF, but the climate-tech umbrella has broadened in recent years. The staying power of energy storage reflects a need for alternative solutions beyond lithium-ion that support longer-duration storage (beyond 4–6 hours). Interestingly, the fact that lithium-ion continues to dominate the electric vehicle light-duty markets, and that the industry recognizes the need for a reliable and clean supply chain of critical materials for energy storage, means that even this stalwart tech topic is already spilling over to other verticals like transportation, materials, and even land use (e.g., for novel mining technologies).

The need for innovation in the electricity sector (e.g., solar or wind) is coming into balance, with other sectors requiring substantial innovation to meet decarbonization goals.

Table 2. Top 11 Technology Subtopics, by Number of Startups Working in Each Space, Represented at the 2023 IGF

Verticals	# Startups
Electricity	
Energy Storage	33
Distributed Energy Resources and Microgrids	27
Solar Photovoltaics	27
Grid Technologies	20
Energy Management and Analysis	19
Demand Response	17
Energy Efficiency and Reduction	16
Wind Power	16
Fuels and Chemicals	
Hydrogen	20
Materials and Manufacturing	
Circular Economy	17
Built Environment	
Energy Efficiency	16

23 https://www.energy.gov/eere/solar/quarterly-solar-industry-update#:~:text=The%20United%20States%20installed%2017.0,GWdc)%20of%20cumulative%20PV%20installations.

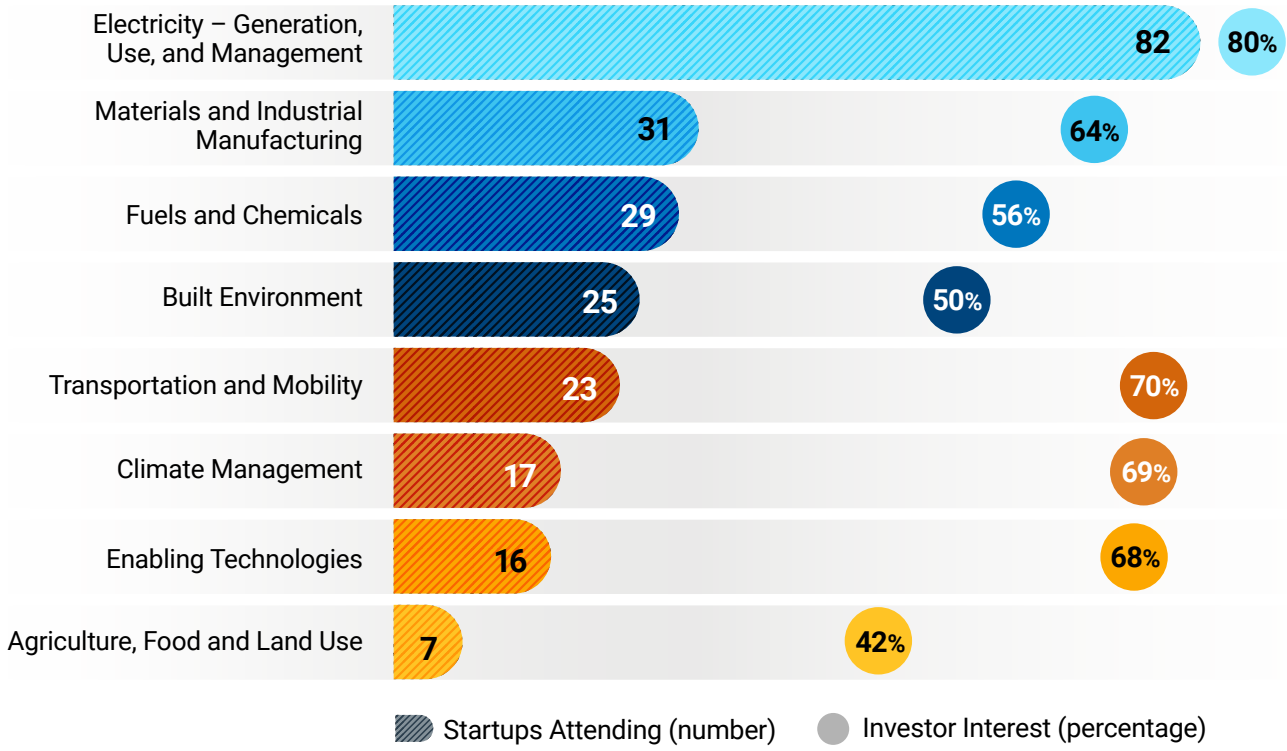

Figure 6. IGF 2023 technologies represented by attending startups and investors. Each startup selected a particular technology category to describe their startup's technology, and attending investors could select multiple categories of interest for investment.

IGF data reflect the broadening of the climate-tech umbrella, with growing populations of startups working on nascent and emerging technologies in verticals like materials and industrial manufacturing; fuels and chemicals; the built environment; climate management; and agriculture, food, and land use. Startups within these sectors work to improve and disrupt existing solutions with the aim of decarbonization.

An examination of numbers of startups in the nascent and emerging sectors highlighted by the funding analysis above shows the startup numbers track with the sector status. Hydrogen, having been past the public-to-private transition defined by equal funding for more than 5 years, was targeted by 21 startups. The more nascent sectors had far fewer startups in attendance: carbon capture (6 startups), geothermal (2 startups), and industrial decarbonization (6 startups[24]). The next few years will show whether these nascent and emerging sectors begin to attract more innovators and investment as predicted.

The IGF also samples investor interest in startup technology areas. Figure 6 features their broad interest, with a vast majority investing in the electricity vertical covering generation, use, and management. This investor interest is displayed against the primary technology selection of each startup—the same startup information as in Figure 5, but with energy storage grouped under electricity. Investor interest and startup representation trend with each other in general at the IGF, with a few exceptions. Investor interest in transportation and mobility, climate management, and enabling technologies ran relatively higher per startup in these sectors.

24 Industrial decarbonization was not offered as a technology subtopic per se, so this figure is the combination of startups working in high process heat (2) and low-greenhouse gas concrete (4).

One outlier is agriculture, food, and land use, where strong investor interest for only seven startups may indicate that investors recognize the potential emissions reductions from agriculture solutions, but the innovative agriculture ecosystem has not yet been fully recruited under the IGF umbrella. Year to year, we anticipate the IGF will continue to witness striking trends in climate-tech innovation, both through the startup and investor lenses. It is through these focused connections between investors and startups that the IGF serves as a dedicated platform to find promising cleantech investment opportunities and a robust lens to gauge innovation.

NREL IEC is Accelerating Startup Technology Commercialization and Fundraising

The NREL IEC convenes a large ecosystem of investors and startups at the Industry Growth Forum but also directly supports startups through technology incubation programs sponsored by private sector partners. Powering technology incubation with NREL's one-of-a-kind research, development, and demonstration facilities and globally recognized researchers, startups can receive third-party technology testing and validation. IEC's flagship technology incubation programs, the Wells Fargo Innovation Incubator[25] and Shell GameChanger Powered by NREL,[26] have collectively supported over 80 companies since 2014. Those companies have gone on to raise over $2 billion in external capital and seen over a dozen exits.[27] IEC programs accelerate a startups' government-enabled to private sector led transitions and catalyze follow on funding.

> Selected startups redeem technical assistance at NREL, leveraging DOE's $15 billion investment in NREL facilities and expertise.

Through each technology incubation program, selected startups join the program cohort and redeem technical assistance from NREL for testing and validation services, leveraging DOE's large and cumulative $15 billion investment[5] in NREL facilities. To support the most promising startups, NREL performs rigorous technical review leveraging both NREL and industry experts with domain expertise leading to cohorts of top-notch startups and a broad portfolio spanning cleantech and climate tech. Startups graduate from the programs having significantly advanced their technology readiness level by 2 levels[28], commonly through prototype testing, development, benchmarking, or demonstration in an operating environment. In turn, this has significant impact on IEC startups' abilities to raise follow-on funding, through private capital and/or public grant funding. Figure 6 shows with quantitative measure the dramatic impact on startups receiving NREL technical assistance through IEC incubation programs.

25 https://in2ecosystem.com.

26 https://gcxnrel.com.

27 Internal IEC data, drawing from PitchBook and portfolio company direct reports.

28 Internal IEC data.

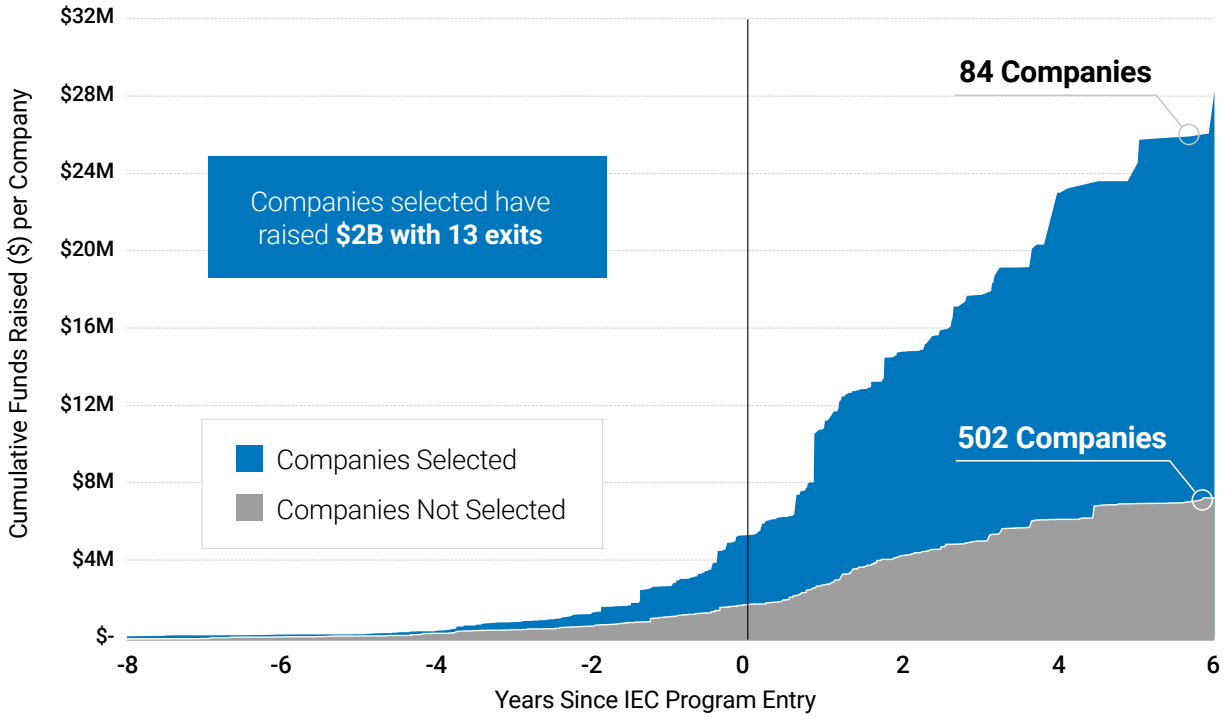

Figure 7. Funding raised by companies selected for NREL IEC technology incubation programs compared against startups that applied but were not selected.

Companies that are selected for NREL's technology incubation programs show a dramatic increased ability to raise follow-on funding, likely indicating critical advancements in technology readiness levels and third-party validation by NREL play a critical role in unlocking more capital to speed the startups' commercialization efforts.

Overall, the IEC functions to build and grow a cleantech ecosystem that speeds technology solutions toward market impact. The IEC does this in three ways: (1) active network management of key stakeholders in the ecosystem, including investors, startups, entrepreneurial support organizations, and industry; (2) convenings throughout the year to facilitate connections among stakeholders to spur startup investment and establish strategic partnerships enabling tech to market; and (3) technology incubation programming with corporate, philanthropic, and government partners, utilizing NREL and other technical institute partners' unique expertise and capabilities to ultimately de-risk technologies for follow-on external investment, demonstration, and deployment opportunities.

> Companies that are selected for NREL's technology incubation programs show a dramatically increased ability to raise follow-on funding

Carbon capture, geothermal energy, hydrogen, and industrial decarbonization are primed and ready for impactful private investment.

Conclusions

This work recognizes the process of technology development through the maturation of funding—from the foundational public funding needed to initialize a new clean energy technology sector, to the large-scale distributed funding provided by private investment. As noted by Jigar Shah, director of the DOE Loan Programs Office, "The clean energy industrial strategy will be private-sector led, government-enabled."[29] Government enablement through basic research and development funding transitions to private-sector market creation and deployment. One strategy to track the timing of that transition for any given technology sector has been shown here and offers up the areas of carbon capture, geothermal energy, hydrogen, and industrial decarbonization as primed and ready for impactful private investment.

As an applied laboratory, NREL drives and co-pilots through the public-to-private funding transition in multiple ways. Industry partners sponsor significant amounts of R&D at NREL that provide a direct pipeline for technical innovations to reach the market. NREL actively recruits innovative startups, providing the funding and framework by which they can leverage NREL expertise to de-risk innovative ideas. Finally, reaching broadly into the cleantech and climate-tech ecosystem, NREL's Industry Growth Forum is a known catalyst for private investment into nascent and emerging technologies. In each of these ways, NREL delivers on its mission of tackling the world's most pressing energy and climate issues, by supporting and enabling the transition of promising technologies from lab to market.

29 https://www.ctvc.co/3-2-1-doe-we-have-liftoff/.

2023 State of Innovation: **Emerging Climate Technologies Primed for Private Investment**

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