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Mission Critical: The Global Energy Innovation System Is Not Thriving

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Accelerating clean energy innovation is critical to avert the worst effects of climate change, but the global energy innovation system is in poor health, with weaknesses across most indicators. Nations must rectify these weaknesses to deliver on the promises world leaders made at COP26.

KEY TAKEAWAYS

- The world needs a healthy energy innovation system to realize future decarbonization commitments. Every part of the system is interdependent and must work together for the system to thrive. Yet there has been little progress since the 2015 Paris Agreement.
- The global energy innovation system stands in weak condition, as evidenced by key indicators of knowledge development and diffusion, entrepreneurial ecosystem, trade, market readiness and technology adoption, and national public policies.
- The only bright spot is the entrepreneurial ecosystem, where early-stage venture capital investments have made a roaring comeback, up 165 percent since 2015.
- Public research, development, and demonstration (RD&D) investments have only risen modestly since 2015 (+29 percent), while the number of high-value patents has gone sideways (+0.2 percent).
- Trade and national policies performed even worse. Nominal clean energy technology exports (+8 percent) have trailed behind global GDP (+13 percent), while the vast majority of effective carbon rates are below the benchmark of EUR60.
- Clean energy consumption is increasing (+23.6 exajoules in the 2010s), but fossil fuel consumption rose even more quickly (+52.6 exajoules) with no sign of abatement in the near future.
- World leaders launched a "Breakthrough Agenda" in Glasgow to spur development and deployment of climate-tech solutions. Now nations must work with the private sector to produce that surge of innovation or the chance to reach climate goals will slip away.

INTRODUCTION

National governments made commitments during the November 2021 United Nations Climate Change Conference (COP26) in Glasgow that will keep the goal of limiting global average temperature increase to 1.5 degrees Celsius only barely "within reach."[1] These promises will ring hollow unless nations act with urgency to accelerate innovation that will make climate solutions feasible, affordable, and reliable in the coming decades. The International Energy Agency (IEA) concluded at Glasgow that "a step-change in action and ambition is needed across all energy technologies and sectors."[2]

Unfortunately, such action has been lacking since the Paris Agreement was signed in 2015. The health of the global energy innovation system is anemic, far from the robust condition the world needs it to be in. Drawing from the findings in the Information Technology and Innovation Foundation's (ITIF's) 2021 Global Energy Innovation Index (GEII), this report evaluates the system across seven indicators:[3]

- Public investment in clean energy research, development, and demonstration (RD&D)
- High-value patents for clean energy technologies (CETs)
- Early-stage venture capital (VC) investments
- Successful clean energy company exits
- CET exports
- Clean energy consumption
- Effective carbon rates (ECRs)

These indicators track many of the global energy innovation system's essential functions. These functions operate interdependently and must all be working well for the system to thrive. While clean energy innovation is seen by a growing number of policymakers as a key element of the response to climate change, many others still focus exclusively on deploying existing solutions. Until that changes and a deep and widespread commitment to a more robust innovation system emerges, progress will be slower than it should and could be.

This report examines the world's aggregate performance across these seven indicators, discusses the gaps in each indicator, and concludes with steps national governments and the private sector are taking to close these gaps.

OVERVIEW: SOME PROGRESS HERE AND THERE, BUT SEVERE GAPS REMAIN

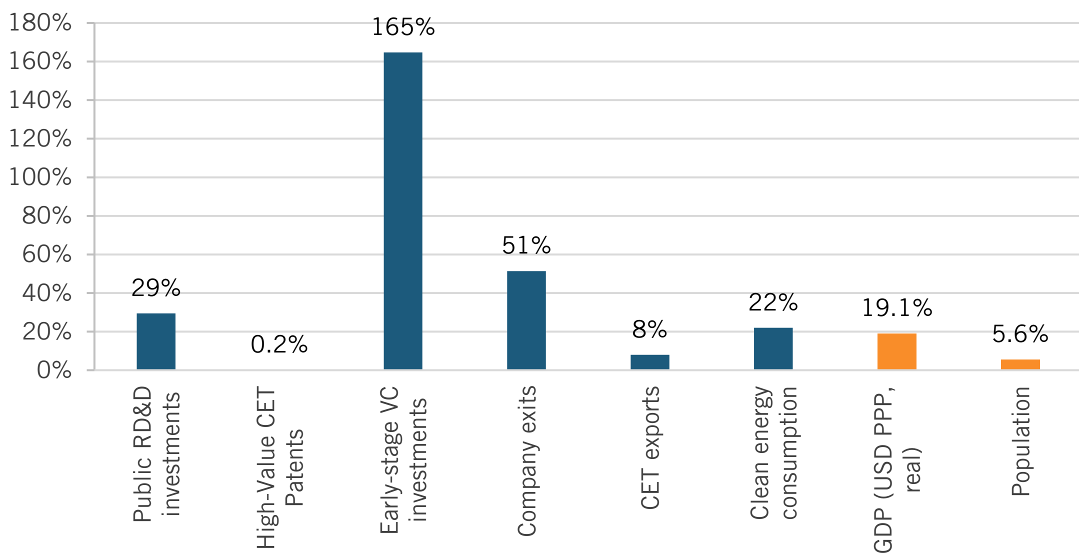
The world has made progress since Paris on some critical climate solutions. The costs of wind and solar power have each fallen significantly, as have those of electric vehicle batteries.[4] Some observers have interpreted these trends as signifying that the world already has the technology it needs to avert climate change, and only lacks the political will to reduce emissions. Such declarations are wildly premature, as ITIF's assessment reveals a system that is not thriving.[5]

This complacency seems to have seeped into national clean energy and climate innovation policies in most nations. Public investments in low-carbon energy RD&D have barely increased as a share of the economy over the past several years. Moreover, most of these investments have gone to more widely deployed technology groups while other clean energy technologies, especially emergent ones that may be important for future decarbonization efforts, have not received RD&D investments on the same scale.

Clean energy patents have gone sideways during this period and international co-invention of patents remains low, while CET exports have increased at a slower pace than the global economy. Clean energy consumption is rising, but not fast enough to offset fossil fuel consumption, which is also growing. And ECRs are too low to accelerate the clean energy transition across all sectors in the major economies.

Entrepreneurial experimentation and early market formation, measured by indicators such as early-stage VC investments in start-ups, have been the only robust elements of the global clean energy innovation system in 2021 (see figure 1) although most of that growth has gone into vehicles. Yet, because the innovation system is deeply interconnected, the ongoing degradation of components will ultimately cause those that are doing well to weaken. Moreover, most VC funding has gone into transportation instead of other clean technologies, and will likely continue to do so given the heightened valuations of electric vehicle companies that have gone public recently.

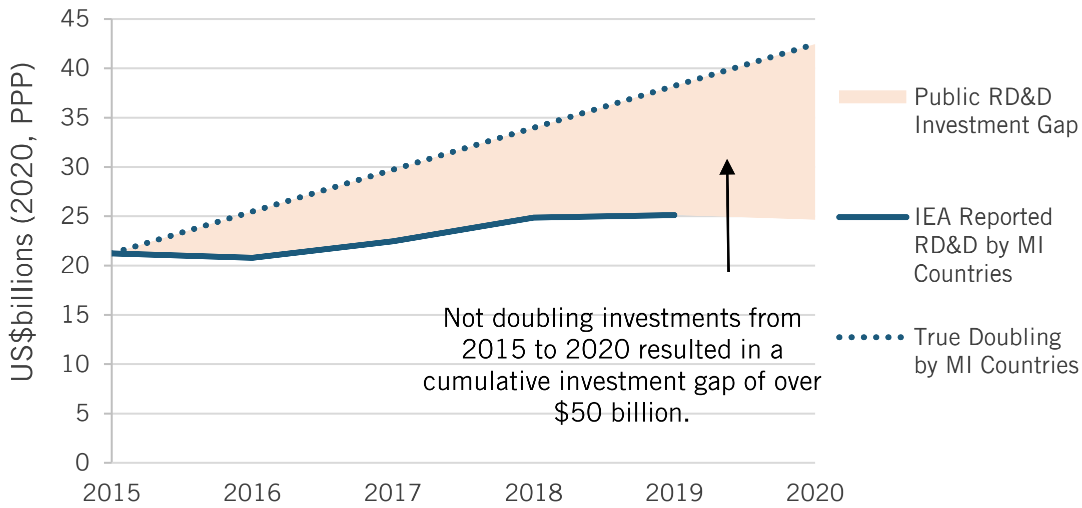
Figure 1: Percentage change in global clean energy innovation system indicators since 2015[6]



INDICATOR 1: PUBLIC INVESTMENT IN LOW-CARBON ENERGY RD&D

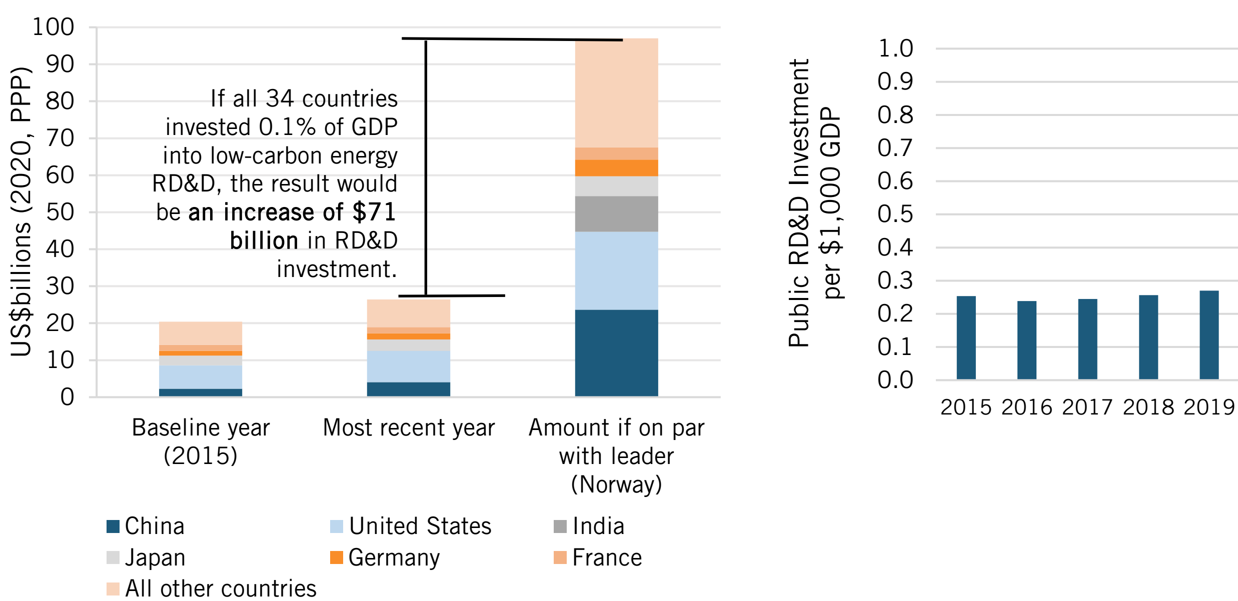
Public investment in low-carbon energy RD&D creates knowledge inventors, entrepreneurs, and technology developers can draw on to develop climate solutions. In 2015, 24 leading nations each adopted the goal of doubling their investments by 2020 in the Mission Innovation (MI) initiative.[7] As a group, they fell far short of the goal. But if every member nation had actually doubled its investment, the cumulative investment by 2020 would have been over $50 billion greater (see figure 2.)

Figure 2: Public investment in low-carbon energy RD&D from MI countries



Only 4 of the 34 countries covered in the GEII (Chile, New Zealand, the Slovak Republic, and the United Kingdom) achieved the doubling goal. In fact, 10 countries had lower RD&D investments in real terms in the most recent year for which data is available than they had in 2015. They included Denmark and Finland, which took the top two spots in the 2021 GEII overall ranking. The United States, which has the largest public RD&D investment by dollar amount, finished eighth place in this category.

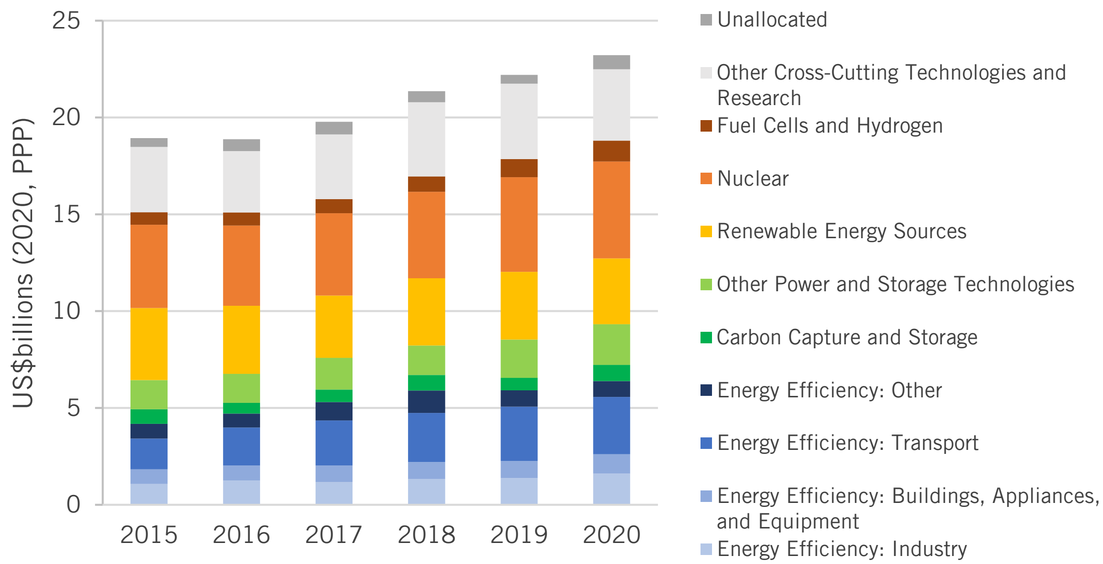
Figure 3: Public investment in low-carbon energy RD&D, benchmark and actual levels[8]



Norway was the only country whose low-carbon energy RD&D investments exceeded 0.1 percent of its gross domestic product (GDP).[9] If all countries in the GEII had followed Norway's example, the global energy innovation system would have received an additional $71 billion per year (see figure 3).

Within the global energy RD&D portfolio, energy efficiency, renewables, and nuclear power are the top categories, accounting for 64 percent of total investment in 2020. (See figure 4.) These technologies are already more widely deployed than others tracked by IEA, yet they can and should be improved substantially. Despite a significant increase in solar and wind energy deployment, fossil fuel consumption has not been curbed, and deployment of renewables has been uneven across the world. Continuous innovation to drive down their costs while expanding their scope (as would be achieved by floating offshore wind farms) will be integral to reaching future climate change goals.[10]

Figure 4: Public RD&D investments by technology[11]



While public RD&D in renewables has trended down, the opposite is true for energy efficiency. The uptick in this category has mainly been driven by a near doubling of investments in the transportation sector (from $1.6 billion in 2015 to $3.0 billion in 2020). Investments in building, appliances and equipment, and industrial energy efficiency, on the other hand, have risen modestly at best (see figure 4.) Yet, buildings are a major driver of energy-related emissions, and industry is the fastest-growing source globally.[12]

Hydrogen and fuel cells and carbon capture and storage (CCS)—relatively nascent technologies—comprise the technology categories with the lowest level of public RD&D investment, accounting for just 8 percent of the 2020 total. To bring these nascent technologies to maturity, which IEA modeling suggests will be vital to achieve climate goals, nations will have to adopt targeted policies, including substantial increases in RD&D investments.[13]

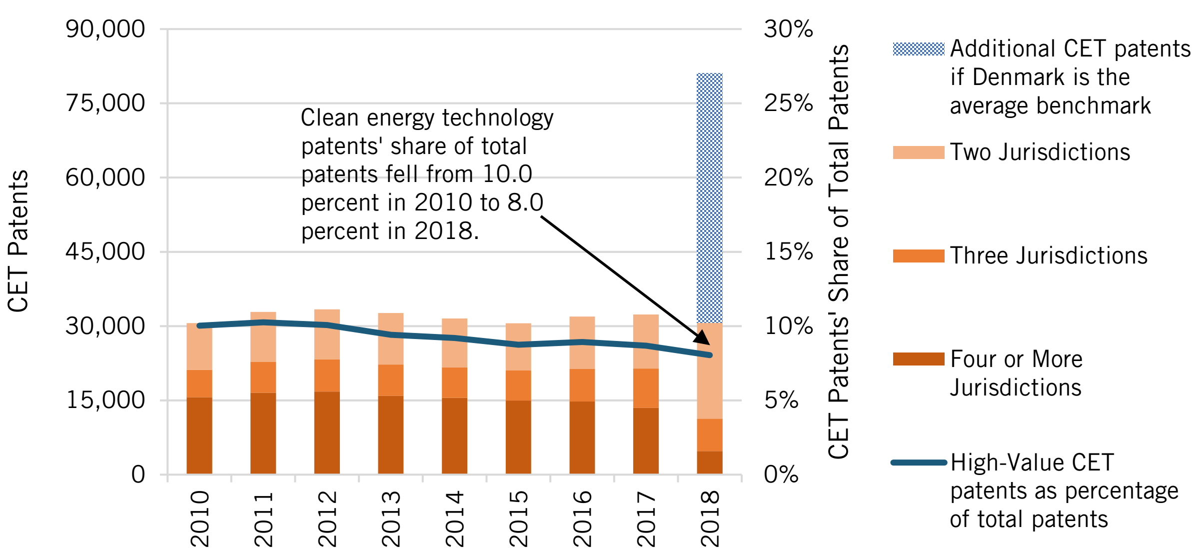
Public RD&D further generates innovation indirectly by stimulating private research and development (R&D). Rather than crowding out privately financed R&D, an increase in public RD&D would correlate with an increase in R&D investment in the private sector. Unfortunately, an overall tepid public RD&D investment in low-carbon energy results in similarly tepid private R&D investment.[14] Indeed, private R&D investment in energy from globally listed companies likewise only rose modestly (just 22 percent) from 2015 to 2020.[15] For example, hydrogen and fuel cells and energy storage collectively received very little public RD&D funding while at the same time accounting for just a small percentage (less than 4 percent) of private R&D investment, although total investment did nearly double during this period.[16]

INDICATOR 2: HIGH-VALUE PATENTS IN CLEAN ENERGY TECHNOLOGIES

Moderate levels of RD&D investment lead to a leveling off of patent filings. Between 2010 and 2018, for example, the number of patents inventors filed for in at least two major jurisdictions, which is how the 2021 GEII defines "high value," was flat (see figure 5.) Moreover, the number of extremely high-value patents (four or more jurisdictions) decreased dramatically in 2018. Relative to all high-value patents, CET patents' share has fallen gradually over time (from 10 percent in 2010 to 8 percent in 2018), indicating that fields other than energy are receiving greater attention from inventors.

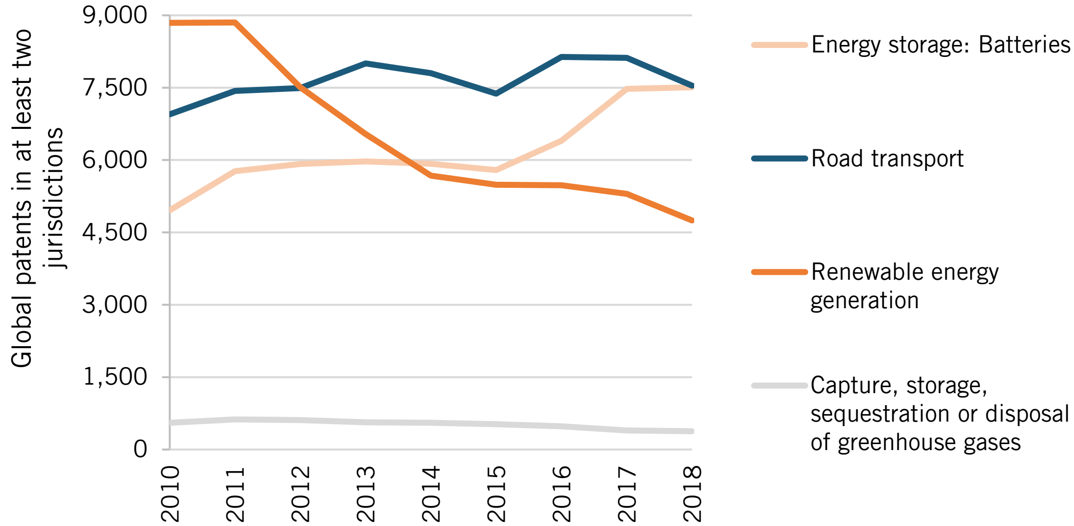
Denmark has led the way on this indicator; high-value CET patents made up 21 percent of all of that country's high-value patents in 2018. If all countries were to follow Denmark's example, there would have been over 80,000 CET patents globally instead of 30,000 (see figure 5) between 2010 and 2018.

Figure 5: High-value patents in clean energy technologies



Unlike public RD&D investment, where energy storage is one of the smallest categories, batteries are one of the largest in CET patents, with about 7,500 granted in 2017 and 2018, up significantly since 2015. (See figure 6.) Road transportation is another major category, with the number of patents remaining consistently high. On the other hand, the number of patents for renewables declined by almost half from 2010 to 2018, a declining trend also observed in public RD&D investment and early-stage VC investment (which is discussed in the next section). Finally, low levels of public RD&D investment in CCS or carbon capture, utilization, and storage (CCUS), electricity transmission and distribution, and hydrogen and fuel cells technologies correlate with low levels of patents in these categories.

Figure 6: High-value clean energy technology patents for select technology groups[17]



Box 1: International Co-invention of CET Patents Remains Low

International collaboration is vital for spurring and strengthening innovation. International co-invention is a form of collaboration that helps detect new business opportunities, increases acquisition of precise knowledge, and creates stronger networks that favor the appearance of new ventures with a global strategy.[18] As companies internationalize production activities, they must acquire strategic assets not available in their home countries.[19]

International co-invention rates in CETs, as measured by patents, are low. Japan and South Korea, which have the highest number of CET patents relative to their economies and populations, also consistently have some of the lowest rates of international co-invention. These rates are also very low among countries with the largest economies and populations, such as the United States (21 percent), China (12 percent), Germany (14 percent), and Brazil (7 percent). On the other hand, co-invention rates are substantially higher among smaller Anglophone countries (Canada, Australia, and New Zealand) and multilingual European countries (Belgium, Luxembourg, Slovakia, and Switzerland), as well as India, all of which have at least 50 percent of co-invention rates.

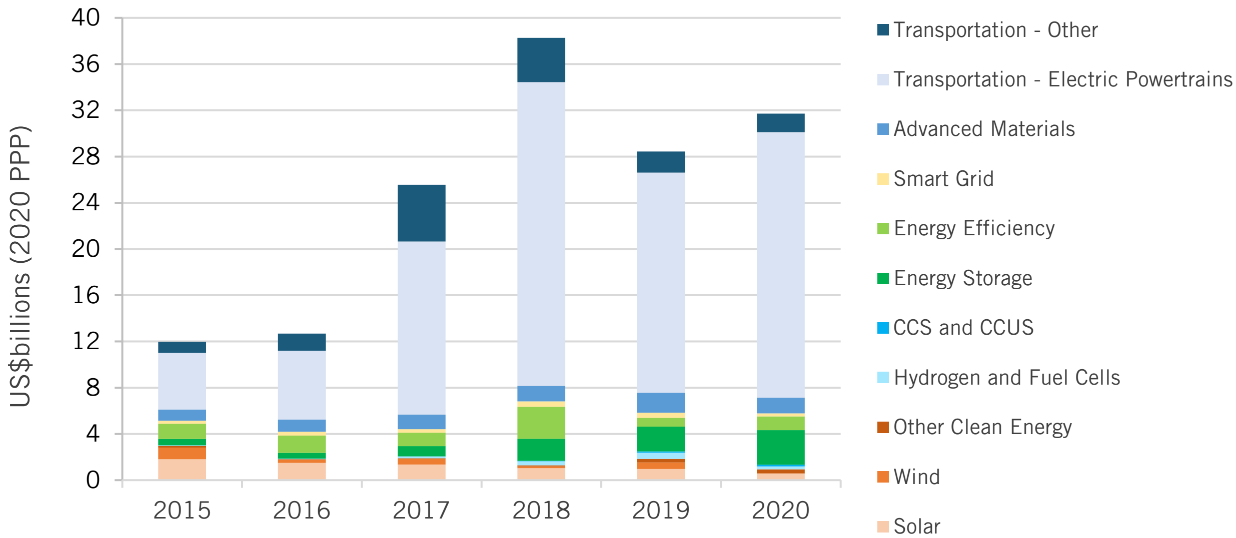
These patterns could represent obstacles to effective knowledge diffusion across countries. For example, other countries could learn from Japan's advanced research on hydrogen and nuclear technologies. But Japan's low degree of engagement in international collaboration in the development of new technologies may hinder the social legitimation of such innovations.

INDICATOR 3: EARLY-STAGE VENTURE CAPITAL INVESTMENTS

Public RD&D investments are the building blocks of innovation. Young firms—typically backed by VC—are often best-positioned to translate knowledge from RD&D into innovations with the greatest potential to reduce emissions.[20] Early-stage VC investments are thus essential to the functioning of the global energy innovation system.

After years of falling VC investments, during the so-called Cleantech 1.0 phase in the first decade of this century, money has been flowing back into cleantech start-ups in recent years.[21] Early-stage VC investment in clean energy start-ups increased almost threefold in 2020 USD PPP (purchasing power parity) from $12.0 billion in 2015 to $31.7 billion in 2020 (see figure 7.)

Figure 7: Early venture capital investments in select clean energy technologies



Other clean energy include: Geothermal, hydro & marine power, and nuclear.

But like public RD&D investments, early VC investments are becoming increasingly concentrated in already large industrial sectors. Specifically, transportation (primarily electric, ride-sharing, and autonomous ground transportation)—already the most popular vertical in 2015—accounted for 78 percent of the total amount invested in 2020, up from 49 percent in 2015. In other words, of the $19.7 billion increase in VC investment from 2015 to 2020, almost of all it ($18.7 billion) was funneled into transportation. Transportation's dominance in early VC investments is similar to the automotive sector's dominance in private R&D investments in energy from globally listed companies.[22]

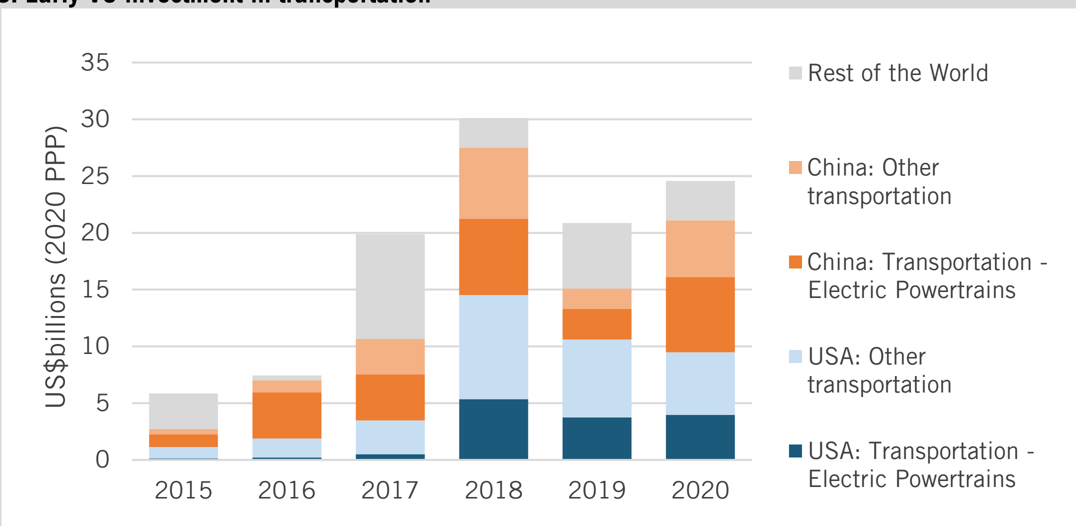
In contrast, clean electricity sectors (such as geothermal, hydro and marine power, nuclear, solar, and wind), which attracted large VC investments in Cleantech 1.0, accounted for just 3 percent of investments in 2020.[23] In absolute terms, these sectors attracted just $0.9 billion collectively, less than one-third of the $3.0 billion they garnered in 2015.

The boom in transportation signals that VC investors are prioritizing technologies with the biggest market potential—and that also have great potential to reduce emissions. In the United States, the electric power sector was the highest-emitting sector during the Cleantech 1.0 period, but it has since been surpassed by transportation. Similar patterns can be seen in many other countries covered in the GEII.[24] VC investors sense a potential gold rush in electric vehicles, which promise to be the next big thing in decarbonization.[25] Many have been rewarded handsomely through successful exits of high-profile companies such as Tesla, Uber, Rivian, and Lucid Group. (See box 2.)

Box 2: Grand Showdown of VC Investment in Road Transportation Between China and the United States Accelerates Innovation

Early VC investment in road transportation has ascended rapidly in both the United States and China. By dollar amount, China invests more than the United States in electric vehicle and other zero-emission vehicle start-ups, while the United States has a greater propensity to invest in other clean transportation start-ups such as those in enabling technologies and e-mobility platforms (see figure 8.) China has an even higher share of early VC investments going to transportation—over 95 percent in every year but one from 2015 to 2020—than the United States does.

Figure 8: Early VC investment in transportation



This competition between China and the United States could be a boon that accelerates innovation in clean transportation. China's big bets are paying off—formerly VC-backed electric vehicle manufacturers such as BYD, NIO, and Xpeng were all poised for another record year in sales in 2021 and have been gaining ground in the electric vehicle sector.[26] In 2020, electric vehicles' market share reached 5.4 percent in China but just 2.2 percent in the United States.[27] China also has a relatively complete battery manufacturing supply chain compared with the United States.[28]

As for the United States, although electric vehicle adoption trails behind China, Tesla, which went public in 2010, has revolutionized the automobile industry as the electric vehicle leader and sparked massive follow-on VC investments in other start-ups. Tesla's innovations, such as an electric drivetrain that is several years more advanced than that of the competition, cutting-edge software, and an extensive supercharging network, have been important catalysts, nudging legacy automobile companies worldwide to innovate, collaborate, and invest billions of dollars in electric vehicles as well.[29]

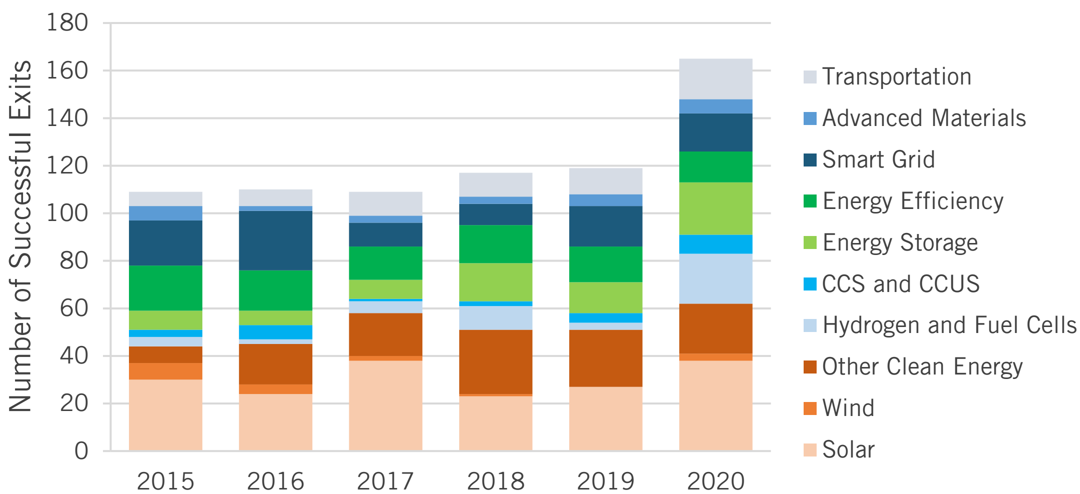
Early VC investments in CCS/CCUS and related technologies, energy storage, and hydrogen and fuel cells technologies accounted for 10.7 percent of global VC investments in 2020, more than double the 5.1 percent they received in 2015. In absolute terms, VC investments in these three technologies jumped over 500 percent from $0.6 billion in 2015 to $3.4 billion in 2020. As clean transportation technologies mature, these three technologies may attract even more VC investment as the next "big thing," with the potential to decarbonize hard-to-abate sectors such as industry and agriculture.

INDICATOR 4: SUCCESSFUL CLEAN ENERGY COMPANY EXITS

Successful company exits are an important part of the global energy innovation system as well. A successful exit signals a firm's growth potential and its high-quality innovations.[30] The number of successful clean energy company exits through private equity deals, mergers and acquisitions (M&A), or initial public offerings (IPOs) has been steadily increasing. M&A accounted for slightly over half of the successful exits between 2015 and 2020.

Solar technology firms account for the highest share of exits globally, but the number of exits by hydrogen and fuel cells, energy storage, and transportation firms has risen the fastest, which suggests that these technologies could be widely deployed in the coming years (see figure 9.)

Figure 9: Successful clean energy technology company exits



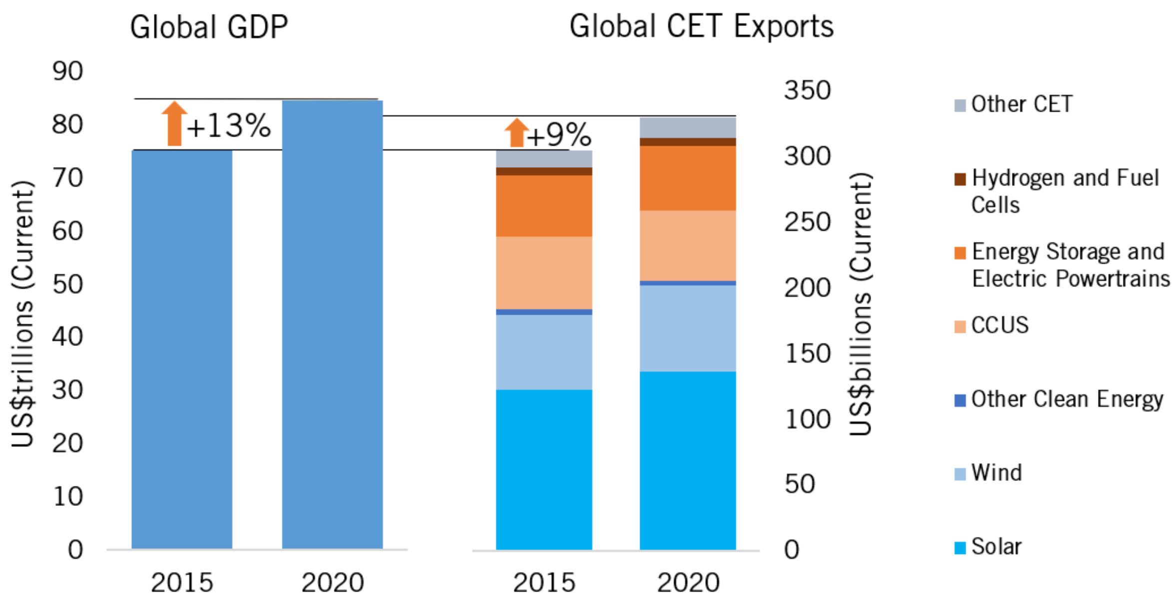
Other clean energy include: Geothermal, hydro & marine power, and nuclear.

Heightened VC investments and successful company exits signal that clean energy innovation has overcome the stigma that followed the bust of Cleantech 1.0. Yet, this is not entirely good news. Recent IPOs of electric vehicle companies such as Rivian and Lucid Group have put the firms' market values above those of large legacy automobile manufacturers such as Ford, General Motors, and Volkswagen, even though they lack fully commercialized products.[31] Such early IPOs have been especially prominent since 2020. An excess of "animal spirits" could signal a frothy market that is heading for a crash. Such an outcome could once again undermine investors' long-term confidence in cleantech start-ups.[32]

INDICATOR 5: CLEAN ENERGY TECHNOLOGY EXPORTS

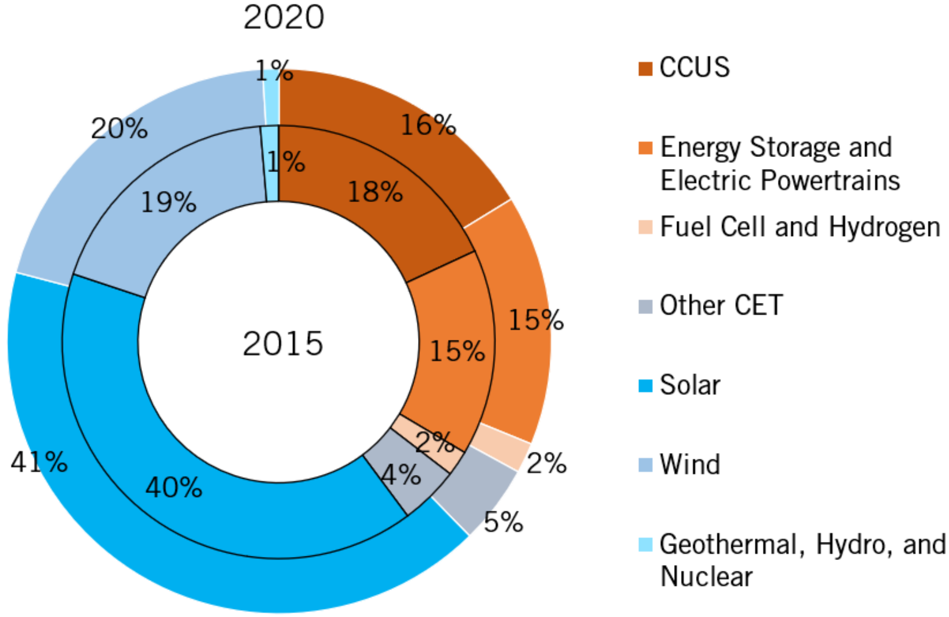
Incremental innovation in established products and services is a vital feature of a healthy innovation system, particularly for a sector as large and essential as energy. The ability of a nation's enterprises to sell what they make in global markets indicates that these enterprises are continuing to improve their products in ways that customers value. CET exports grew by 8 percent in 2020 compared with 2015 globally in nominal value, but global GDP grew 13 percent during the same period (see figure 10).[33]

Figure 10: Global clean energy technology export growth fell behind global GDP growth



Solar is the largest category of CET exports, accounting for 41 percent of the global total in 2020. Wind accounted for another 20 percent. China has dominated the export of solar technologies for several years, holding a steady share of one-third of the global total. Altogether, solar and wind's share of clean energy exports rose from 59 percent in 2015 to 61 percent in 2020 (see figure 11.) Surprisingly, CCUS (16 percent), and energy storage and electric powertrain (15 percent) hold the next two spots (each accounting for about $50 billion in exports), despite receiving relatively little public RD&D and VC investment. On the other hand, hydrogen and fuel cells totaled just shy of $6 billion in exports (2 percent). As clean hydrogen gains traction as a climate solution, exports may need to accelerate to meet emissions reduction goals.

Figure 11: Global clean energy technology exports percentage breakdown[34]



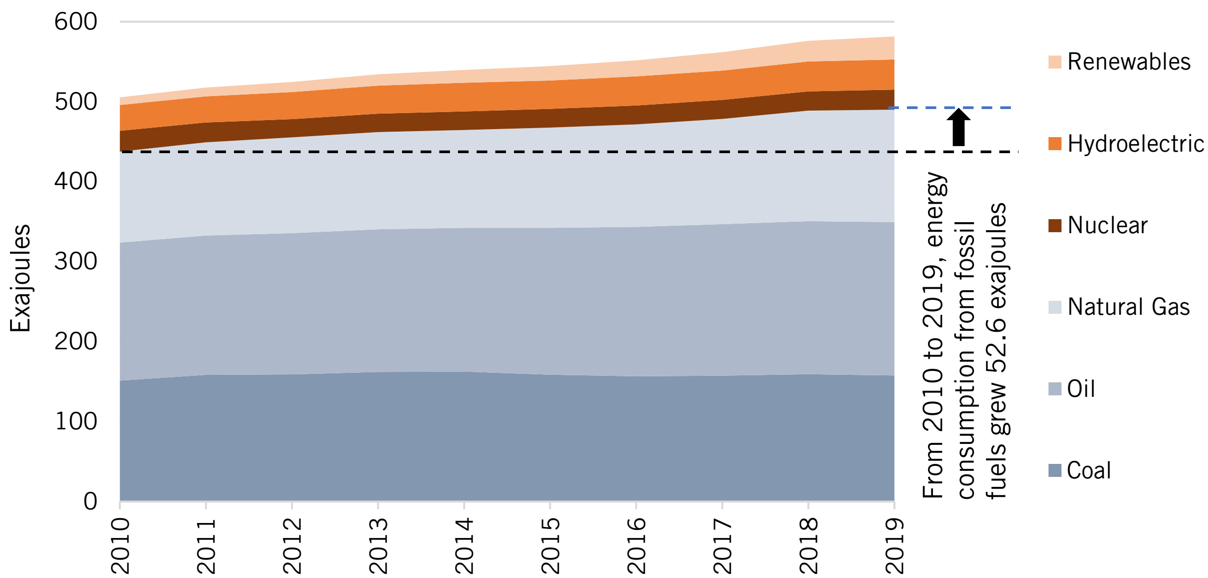
Other CETs include insulation (energy efficiency) and smart meters

In addition to having the most patents, Denmark has the highest export propensity (export as a percentage of GDP) in the GEII—1.6 percent in 2020. That figure is a large decline from 2.4 percent in 2015. If every country had Denmark's export propensity in 2015, CET exports would be about six times greater than they were. Czechia, Hungary, Slovakia, and Slovenia—all Central European countries—also have high CET exports relative to GDP, especially CCUS, energy efficiency, and energy storage technologies. These are export-oriented countries with strong integrations in global supply chains.[35]

INDICATOR 6: CLEAN ENERGY CONSUMPTION

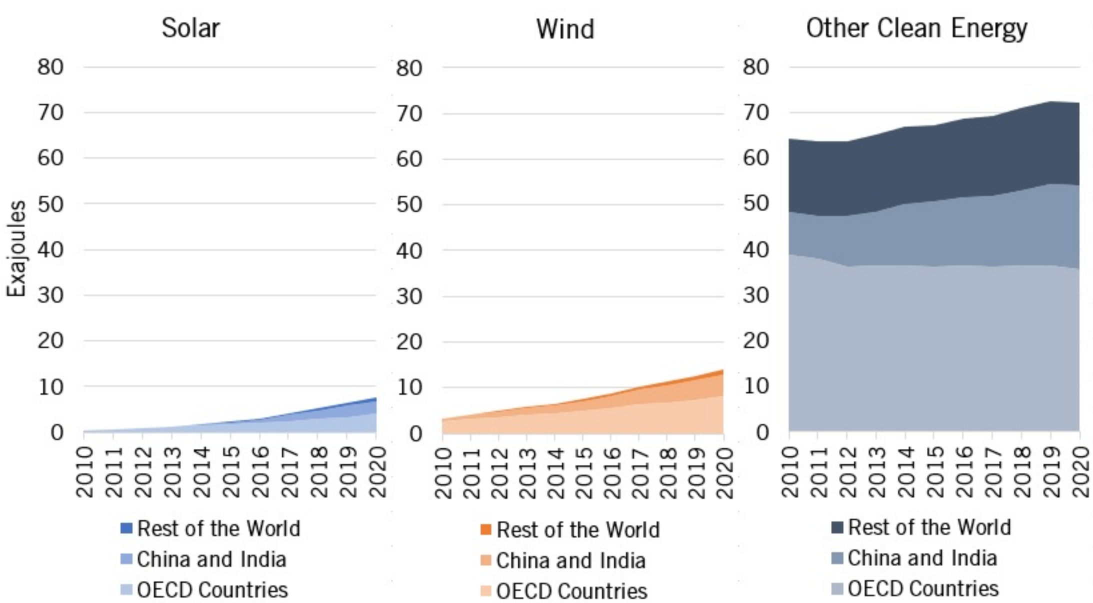
Clean energy consumption helps drive innovation by providing a demand pull on providers of CETs. It provides the revenue that funds private RD&D and the scale that supports learning and scale economies. The success of renewables in recent years has driven down fossil fuels as a share of global energy consumption. In 2019, for instance, these greenhouse gas-emitting resources made up 83.5 percent of the world's energy, down from 86.6 percent in 2010.

Figure 12: Global primary energy consumption[36]



However, clean energy consumption is not growing faster than total energy demand in absolute terms, which means fossil fuel consumption is continuing to rise even though its share of the total has fallen. From 2010 to 2019, clean energy consumption grew 23.6 exajoules, but fossil fuel consumption grew 52.6 exajoules (see figure 12.)[37] Major developing economies, as well as high-income Australia, Canada, and New Zealand, consumed more fossil fuels throughout the 2010s.

Figure 13: Global clean energy consumption[38]



Most global clean energy consumption comes from relatively mature technologies such as hydroelectric and nuclear. Solar and wind technologies, while growing rapidly, are still largely confined to the Organization for Economic Cooperation and Development (OECD) countries, China, and India (see figure 13.) Yet, the rest of the world still makes up 25 percent of global energy consumption. Until these countries gain deployment-induced experience with renewable technologies, their costs may remain above those in the leading countries.

This indicator contains a couple other bits of good news: Led by Bhutan, small developing countries are the overlooked leaders of clean energy consumption.[39] And global energy consumption per capita decreased slightly pre-pandemic from 75.9 exajoules per billion people in 2018 to 75.8 exajoules per billion people in 2019. Energy-efficiency gains help make such reductions possible without decreasing energy services received. But the trend cannot be sustained without continuous innovation.

INDICATOR 7: EFFECTIVE CARBON RATES

A carbon price incorporates some or all of the costs climate change imposes on society into the cost of fossil fuel energy and other climate-unfriendly products and services. Such a price signals a societal preference for clean energy and provides a market pull that complements RD&D and incentivizes greater private sector investment.

The ECR is a standardized measure for carbon pricing.[40] It consists of three components: fuel excise taxes, carbon taxes, and tradeable carbon emission permits. According to research published by OECD, an ECR of 60 Euros per ton of carbon dioxide in 2020 indicates that a country is on track to reach the goals of the Paris Agreement by midcentury.[41] But the GEII shows that ECRs are well below this benchmark. Less than 19 percent of emissions across 44 OECD and G20 countries faced a price per ton of 60 Euros or more in 2018 (see table 1).[42]

Table 1: Carbon pricing score by sector at the EUR 60 benchmark[43]

Sector	Bottom-performing country	Top-performing country	All countries
Road	4.5%	100%	79.9%
Agriculture and fisheries	0%	100%	38.2%
Off-road	0%	98.9%	24.7%
Residential and commercial	0%	88.8%	9.9%
Industry	0%	59.3%	5.2%
Electricity	0%	49.0%	5.1%
All sectors	1.3%	69.3%	18.7%

Because the fuel excise tax is a component of the ECR, countries generally performed the best overall in road transport. However, this tax is not intended to reduce emissions, but rather to fund transportation and other government programs. It is an "accidental carbon tax."[44] Outside the road sector, progress is severely lagging. ECRs are particularly low in the electricity and the industrial sectors, even though they are among the largest greenhouse gas-emitting sectors globally.

TIME IS RUNNING SHORT; THE WORLD MUST ACT NOW TO TURN CLIMATE PROMISES INTO REALITIES

The world promised progress at COP26. Now it must turn those promises into reality. So far, nations have fallen far short of their commitments to meet the goals of the Paris Agreement, resulting in an ever-growing emissions gap.[45] This emissions gap is in part a product of an innovation gap, an inevitable outcome of a global energy innovation system that is not healthy enough to drive innovation as quickly as it is needed.

But there is hope. World leaders launched a new "Breakthrough Agenda" in Glasgow, a commitment endorsed by more than 40 countries to work together internationally in the 2020s to accelerate the development and deployment of clean technologies and sustainable solutions needed to meet the Paris Agreement goals.[46] MI entered a new "2.0" phase in 2021, with member countries striving to accelerate the frontiers of innovation and drive down the cost of technologies by driving public-private action.[47]

In the private sector, an increasing fraction of global financial services firms have agreed to align their financial assets with the climate goals set out in the Paris Agreement.[48] Electric vehicle sales are on track to almost double year over year, and automakers have increased their commitments to zero-emission vehicles.[49] Renewables are set to account for almost 95 percent of the increase in global power capacity through 2026; total capacity added from 2021 to 2026 is expected to be 50 percent higher than it was from 2015 to 2020.[50]

But time is running short. It is time for activists, non-governmental organizations, thought leaders, and policymakers to cease the narrative that we already have all the technologies we need and only lack the will to force people and companies to use them. Even if we did have all the technologies we need (which we don't) widespread global adoption is not possible with further price declines—and that requires more innovation. If national governments, in collaboration with the private sector, fail to close the innovation gap by rejuvenating the global energy innovation system, climate goals that today are within reach, albeit barely, will quickly slip away.

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About the Author

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About ITIF

The Information Technology and Innovation Foundation (ITIF) is an independent, nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized by its peers in the think tank community as the global center of excellence for science and technology policy, ITIF's mission is to formulate and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress.

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ENDNOTES

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6. The bar chart displays percentage change in each indicator from 2015 (the base year) to 2020, unless otherwise noted. Public RD&D investments are based on the most recent year data is available. 2018 is the latest year for which high-value CET patents are available.
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32. As a technological revolution moves to the maturity phase, the market for the new technology becomes saturated, and investment opportunity dwindles. This is the last stage of the technological revolution, and financial capital cycle as described in Carlota Perez' work in innovation and financial dynamics: http://www.carlotaperez.org/.

33. Figure excludes re-exports, which are foreign goods exported in the same state as previously imported, from the free circulation area, premises for inward processing or industrial free zones, directly to the rest of the world and from premises for customs warehousing or commercial-free zones, to the rest of the world. The United Nations Comtrade Database does not list every country; some countries are aggregated into groups. Furthermore, the components of the group vary by reporter, trade flow, year, and commodity. Therefore, it is not possible to accurately convert the CET export amount from nominal current US dollars to PPP-adjusted US dollars using 2020 as the base year.

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37. The discussion excludes 2020 due to COVID-19, which resulted in significantly decreased consumption. The decrease in consumption in 2020 mostly came from the reduction in fossil fuel consumption. However, the inclusion of 2020 in the discussion would be positively biased as consumption in 2021 has mostly bounced back, with most of that coming from fossil fuel.

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39. The data source does not disaggregate these countries from the broader regions. However, international energy consumption data from the Energy Information Administration (EIA) for 2018 shows that 80 percent of Bhutan's energy consumption comes from nuclear and renewables. Outside Bhutan, the following small Latin American and African countries stand out: Costa Rica (46 percent), Panama (44 percent), Paraguay (77 percent), Uruguay (55 percent), the Democratic Republic of the Congo (72 percent), Malawi (44 percent), Mozambique (52 percent), and Zambia (57 percent).

40. Effective carbon rates (ECRs) are the sum of taxes and tradeable permits that effectively put a price on carbon emissions. There are three benchmark ECRs: EUR 30, EUR 60, and EUR 120. EUR 30 was the low-end price benchmark of carbon costs in the early and mid-2010s, while EUR 120 is a central estimate of the carbon price needed in 2030 to decarbonize by midcentury under the assumption that carbon pricing plays a major role in the overall decarbonization effort. The discussion here uses EUR 60 as the benchmark.

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