ECONOMIST IMPACT

Zeroing in: Fostering innovative technologies for a net-zero future

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About this report

Zeroing in: Fostering innovative technologies for a net-zero future is a report commissioned by Invesco and written by Economist Impact. This report explores four key technologies that will play a crucial role in the path to net zero—carbon capture, usage and storage (CCUS); hydrogen; grid-scale energy storage; and advanced nuclear—and the opportunities and challenges of scaling each of them. The findings are based on an extensive literature review and interview programme conducted by Economist Impact between July and October 2021.

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To supplement the survey results, Economist Impact conducted an interview programme with clean energy and decarbonisation experts between August and September 2021, with the aim of validating and guiding our research. Our thanks are due to the following experts for their time and valuable insights:

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About this report

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Foreword

Even amidst the tumult of a global pandemic over the past two years, climate change has retained its status as the single greatest threat to our planet and its inhabitants. In turn, the transition to a net-zero energy system continues to present one of the most pressing and far-reaching tasks confronting humanity.

As this report highlights, the journey ahead of us is likely to be long and complicated. From an investment perspective, the sums required to bring about the desired transformation are enormous–yet they are comprehensively dwarfed by the projected returns. The challenge provides an opportunity to demonstrate the capacity of responsible investing to deliver financial and non-financial outcomes alike.

It is sometimes suggested that viewing a phenomenon such as global warming through the prism of investing is to trivialise it. We see no logic in such arguments. The fact is that responsible investing is crucial to bringing about urgently needed change. In the quest to develop a genuinely green economy, as in any sphere, the best ideas must be supported by capital if they are to fulfil their potential.

This does not mean that the investment community alone can safeguard the future. It is true that many goals intended to serve the greater good cannot be achieved without investors, but it is also true that investors cannot accomplish them without the participation of others–policymakers perhaps foremost among them.

Many of the barriers to progress identified in this report underscore the need for multi-stakeholder collaboration. The broader application of carbon capture and storage, hydrogen, grid-scale energy storage and advanced nuclear energy has been hindered by factors including the lack of infrastructure, insufficient government subsidies, regulatory and market inertia and, of course, high costs.

These concerns are likely to take years to disentangle and address. It is already clear that the transition to a net-zero energy system will entail myriad second- and third-order ripple effects, and that it will continue to pose tremendously difficult problems whose solutions might be equally multifaceted and even counterintuitive.

The line between the relative certainties of incremental innovation and the enhanced risks and rewards associated with radical change will be a constant consideration as this journey unfolds during the coming years and decades. So, too, will the balance between the near term and the long term.

When will tipping points occur? How might we recognise or even anticipate them? Which assets could become stranded? Which novel technologies will endure and which will themselves be rendered obsolete in comparatively short order? These and many other questions remain to be answered.

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We should be under no illusions about the scale and complexity of the challenge. At the same time, though, we should clearly recognize what it represents: a sustainable future and an unprecedented, fascinating, multi-trillion-dollar opportunity to capture growth as the world economy moves into an entirely new phase.

On behalf of everyone at Invesco, I would like to thank Economist Impact for preparing this report. I would also like to thank the various contributors for their time and valuable insights. I hope that after reading this report you will agree that the transition to a net-zero energy system demands our attention and backing – both as investors and as global citizens.

Dr Henning Stein
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The state of net-zero energy

Without immediate, rapid and large-scale reductions in greenhouse gas (GHG) emissions, limiting warming to close to 1.5°C or even 2°C will be beyond reach, the Intergovernmental Panel on Climate Change (IPCC) warned in August 2021.[1] Transitioning to a net-zero energy system is critical to achieving this goal.

To limit global warming to 1.5°C above pre-industrial levels, countries must cut GHG emissions from 59.1 gigatons of CO_2 equivalent ($GtCO_2e$) per year in 2019 to 25 $GtCO_2e$ by 2030, and transition to net zero by 2050 at the very latest—a drop of nearly 60%.[2] By September 2021, 63 countries, representing 54% of global GHG emissions, had communicated net-zero emissions targets, including the US and China, which have embedded these in policy documents.[3] The EU and 11 further countries, including Japan, the UK and Canada, have enshrined in law a net-zero target by 2045 or 2050. Meanwhile, Suriname and Bhutan have already achieved net zero.[4]

The energy sector is the largest emitter of GHGs and has the largest potential to cut emissions, contributing 33 $GtCO_2e$ in 2021 alone.[5] By transitioning to renewable and other low-carbon energies and increasing energy efficiency, this sector (excluding nuclear) has the potential to cut 12.5 $GtCO_2e$ a year, or 38%, according to UNEP.[6]

What is a net-zero energy system?
The term net zero refers to a state of equilibrium between the amount of carbon emitted into the atmosphere and the carbon removed from it.[7] As part of the transition to net zero, energy systems play a significant role. The energy system links energy supply with energy demand through final energy carriers, including electricity and liquid, solid or gaseous fuels.[8]

However, achieving net-zero ambitions will require a host of technologies that go beyond renewable energy, from enabling technologies to accommodate variable renewable energy onto more flexible grids, to carbon capture and removal to restrict and reduce GHG emissions from the atmosphere, artificial intelligence and smart energy management. Some technologies are more controversial. Advanced nuclear fission, and more distant fusion, can be key to emission-free energy over the long term. If we fail to mitigate the effects of climate change in time,

[1] https://www.ipcc.ch/site/assets/uploads/2021/08/IPCC_WGI-AR6-Press-Release_en.pdf
[2] https://www.unep.org/interactive/six-sector-solution-climate-change/
[3] https://www.climatewatchdata.org/net-zero-tracker
[4] https://eciu.net/netzerotracker
[5] https://www.iea.org/reports/global-energy-review-2021/co2-emissions
[6] https://www.unep.org/interactive/six-sector-solution-climate-change/
[7] https://energysavingtrust.org.uk/what-is-net-zero-and-how-can-we-get-there/
[8] https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter2_Low_Res.pdf

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then measures to reverse them, such as solar or carbon geoengineering, may become necessary.

While most emissions reductions through 2030 can come from technologies already on the market, almost half the reductions needed by 2050 will come from technologies that are currently at demonstration or prototype phase (see Figure 1).[9]

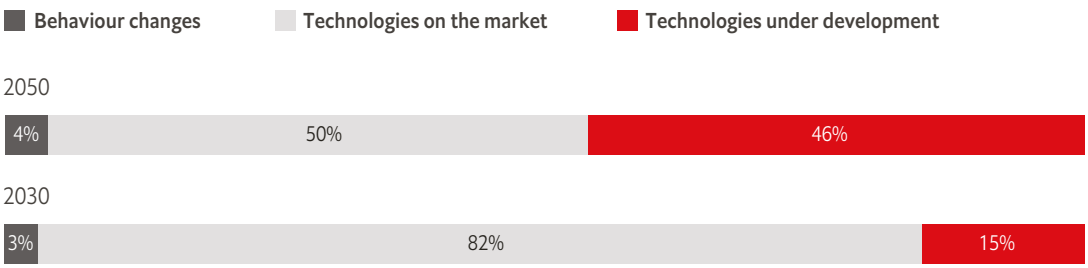
Major innovation is needed this decade to bring these new technologies to market and scale them in time.[10] Some of the most significant innovation opportunities today concern advanced batteries, hydrogen electrolysers, and direct air capture and storage. Innovation through research, development, demonstration and deployment must be accompanied by large-scale construction of the infrastructure needed. This includes new pipelines to transport captured CO_2 emissions and systems to move hydrogen.

Current energy transition investment plans call for an increase from US$33 trillion to US$131 trillion between now and 2050 to reach the 1.5°C scenario. This US$98 trillion jump in investment could ultimately yield a total return of at least US$61 trillion by 2050.[11] Sharp adjustments in capital flows and a reorientation of investments are necessary to align energy with a positive economic and environmental trajectory.

This report provides an initial exploration of key investment opportunities in technologies that can pave the way towards net zero. It looks at four technologies—**carbon capture, usage and storage (CCUS); hydrogen; grid-scale energy storage;** and **advanced nuclear**—that play an important role in decarbonisation. While the road to net zero will rely on a range of solutions, exploring the four highlighted in this report will facilitate future conversations about next-generation net-zero technologies. This report explores the opportunities and challenges of scaling each technology, concluding with a review of financing models that could unlock the necessary funds for deployment. These include the role of governments in de-risking the roll-out of net-zero infrastructure assets, and public financial instruments to mobilise funds. In the private sector, venture capital plays a vital role in the rapid commercialisation of proven technologies, and crowdfunding is a growing source of investment in clean energy.

Figure 1. Still in the pipeline

Key contributors to annual CO_2 emissions savings in the net-zero pathway, relative to 2020



Source: International Energy Agency (IEA), 2021

[9] https://www.iea.org/reports/net-zero-by-2050
[10] https://www.iea.org/reports/net-zero-by-2050
[11] https://www.irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook

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Carbon Capture and Storage: market limitations hindering progress

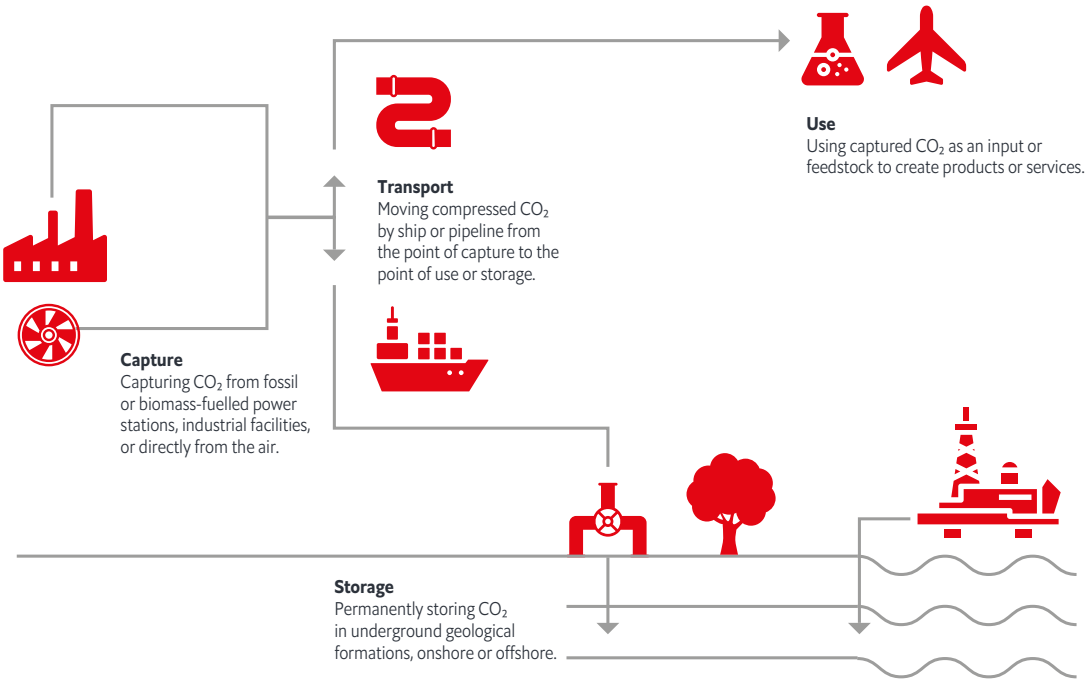
A raft of technologies are in use or being developed to capture CO_2 emitted during power generation and industrial processes, and either use it or store it permanently underground.

Technologies are also being developed to remove CO_2 from the atmosphere—including bioenergy with carbon capture and storage (BECCS) and Direct Air Capture (DAC)—resulting in negative emissions. The IEA estimates that by 2070, most CO_2 will be captured from gas, coal and biomass plants, with a small amount from DAC.[12] However, some experts warn against relying on removal technologies to offset emissions, saying they should primarily be used to remove legacy emissions.[13]

Some CO_2 capture technologies have been used by the fossil fuel industry for decades, but many—particularly removal technologies—are still at pilot stage. For example, some pilot green energy plants—like Haru Oni in Chile, being built

Figure 2. Capturing carbon

An overview of how carbon capture works



Source: International Energy Agency (IEA), 2021

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with German funds—are using DAC technologies to convert removed CO_2 into fuel[14] while aircela is developing small solar-powered DAC units that can be used domestically to produce e-fuel.[15]

Current CCUS capacity: 40 MtCO2/year

↓

Required capacity by 2030: 800 MtCO2/year

Existing CCUS facilities can capture more than 40 $MtCO_2$ a year.[16] However, to make a noticeable contribution to net-zero emissions, this must increase to 800 $MtCO_2$ a year by 2030 and continue to accelerate.[17]

Yet the greatest barrier to scaling up CCUS technologies is the lack of market for captured and removed CO_2. While there is an estimated US$6 trillion global market available to use CO_2 for producing materials like plastics and cement, or in the food and beverage sector, most captured and removed CO_2 will need to be stored underground, limiting market opportunities.

Overcoming barriers

The cost of conventional post-combustion capture can fall significantly. Well-capitalised companies are developing novel technologies and power cycles, (e.g., Allam-Fetvedt Cycle)[18], new tech approaches (e.g., electrical swing adsorption)[19], and improving heat recovery and process intensification.

Government policies can also play an important role in the development of a sustainable and viable CCUS market. In the US, for example, the 45Q tax credit, offered per metric tonne of qualified CO_2 captured and permanently stored or used, is intended to incentivise investment in CCUS.[20] The California Low Carbon Fuel Standard[21] requires transportation fuels to meet energy related GHG targets.[22] Together they have spurred new investment plans by helping to create a market in the US.

Governments also need to underwrite investment in CO_2 transport and storage infrastructure where it does not already exist. Planning and building the infrastructure can take as long as ten years, so work must start now.[23] Capital grants and operational support can also boost investment and drive widespread

[12] https://www.iea.org/reports/about-ccus
[13] Interviews with Erin Burns, executive director of Carbon180, and Klaus Lackner, professor at the School of Sustainable Engineering and the Built Environment at Arizona State University
[14] https://www.siemens-energy.com/global/en/news/magazine/2021/haru-oni.html
[15] https://aircela.com/systems2
[16] https://www.iea.org/reports/about-ccus
[17] https://www.iea.org/reports/ccus-in-clean-energy-transitions/accelerating-deployment
[18] The Allam-Fetvedt cycle is a way of burning natural gas that emits no emissions into the atmosphere. CO2 is a by-product of the process which is pipeline ready for re-use or storage. NET Power, which has used this technology at a plant in La Porte, Texas, says it produces low-cost clean electricity. https://netpower.com/technology/
[19] Electrical Swing Adsorption is a direct air capture technology https://www.advancedsciencenews.com/electro-swing-direct-air-capture/
[20] https://sgp.fas.org/crs/misc/IF11455.pdf
[21] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard
[22] https://sgp.fas.org/crs/misc/R46835.pdf
[23] https://www.iea.org/reports/ccus-in-clean-energy-transitions/accelerating-deployment

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deployment in the near term.[24] According to IEA estimates, capital grants ranging from US$55 million to US$840 billion have been awarded since 2010.

Some examples of government supported CCUS projects include Drax, a former major UK coal power station, that has switched to renewable energy. It is working towards deploying the world's largest carbon capture project by fitting BECCS units to remove at least 8 $MtCO_2$ from the atmosphere each year.[25] The Norwegian government is funding the development of a project that captures CO_2 at a cement factory and waste-to-energy plant and stores it under the North Sea in a facility that is being developed by fossil fuel companies.[26]

While great strides have been made in CCUS in recent years, progress is skewed geographically. Only two countries—the US and Canada—are making tangible progress while others trail behind. To boost the market for captured and removed CO_2, there is a need to expand progress globally.

[24] https://www.iea.org/reports/ccus-in-clean-energy-transitions/accelerating-deployment
[25] https://www.drax.com/about-us/
[26] https://ccsnorway.com/

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Hydrogen energy: huge potential, high costs

One technology that has gained significant momentum in recent years is hydrogen. Hydrogen "burns clean", producing only water, electricity, and heat when consumed as a fuel, with limited to zero emissions.

It can be used directly in industrial processes or for combustion in an engine, or to provide electricity via a fuel cell. But its ability to curb emissions depends on *how* it is produced. There are four key methods of producing hydrogen (see Figure 3).

Figure 3. The many shades of hydrogen
Common hydrogen production pathways being explored

	Production process	Feedstock and energy source	Pros	Cons
Grey	Produced by steam methane reformation without CCUS	Feedstock: natural gas, gasified coal	Lowest cost, abundant	Highest carbon intensity
Blue	Produced from fossil fuels by steam methane reformation, pyrolysis or other processes with CCUS	Feedstock: natural gas, coal, crude bitumen	Low-cost, abundant, low carbon intensity, pyrolysis offers scale and siting flexibility	SMR pathway siting is constrained by CCUS, feedstock is not renewable
Green	Produced from water by electrolysis using renewable energy such as hydroelectricity, wind or solar	Feedstock: water Energy source: renewable electricity	Lowest carbon intensity, scalable	Highest cost, opportunity cost - competes with electrification demand
Nuclear	Produced from water by electrolysis or high temperatures from nuclear energy	Feedstock: water Energy source: Uranium/nuclear electricity	Low carbon intensity	Limited availability and siting constraints

Source: Government of Canada, 2020

[27] Steam methane reformation is a process through which methane from natural gas is heated, with steam, usually with a catalyst, to produce a mixture of carbon monoxide and hydrogen; https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

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Over 90% of current global production is "grey" hydrogen, produced from fossil fuels such as natural gas, coal and oil using a process called steam methane reformation.[27] While its low cost, which starts at US$0.7/kg,[28] is appealing, "grey" hydrogen emits over 800 $MtCO_2$/yr, equivalent to the annual CO_2 emissions of Indonesia and the UK combined.

The same process combined with CCUS technologies to capture the carbon-based by-product produces "blue" hydrogen, which still results in emissions escaping into the atmosphere, notably from the production of the feedstock fuel itself.[29] While some researchers argue that "blue" hydrogen may be more carbon intensive than burning natural gas or coal for heat, the consensus is that CO_2 emissions are lower.[30]

Emission-free "green" hydrogen is produced with renewable energy (such as hydroelectricity, wind or solar power) to electrolyse water. This results in zero emissions but is two to three times more costly than "blue" hydrogen, ranging from US$2.50/kg to US$6.80/kg.[31] Such figures are driven mainly by the cost of renewable electricity and electrolysis facilities,[32] and explain why "green" hydrogen accounts for only 4% of global energy production.[33]

Nuclear power and biomass are also being explored to produce low-carbon hydrogen, but these options are at a very early concept stage.[34]

When produced without significant emissions, hydrogen is a versatile tool to decarbonise a wide range of sectors. Currently, it is mostly used in oil refining and fertiliser production, but it can play a key role in decarbonizing the power sector (as a medium to store or ship clean electricity) and also harder-to-abate sectors including transport, shipping, and heavy industry (such as steel).

Hydrogen fuel cell electric vehicles are already in the market today, with offerings by Toyota and Hyundai, but it will likely be most competitive in heavy transport sectors. In September 2021, Airbus announced a new zero-emission concept aircraft using "green" hydrogen as a primary energy source, citing this clean aviation fuel as a likely solution for the aerospace sector to meet its climate-neutral targets.[35]

Further innovation is necessary to overcome challenges relating to hydrogen's relatively low density. It requires three times more storage infrastructure than gas for the same energy value and would need to be highly condensed to be viable in a commercial airliner. [36][37]

Looking ahead

Hydrogen could meet up to 24% of the world's energy needs by 2050,[38] but government targets and support are needed to create demand, drive down "green" hydrogen production costs, and build the necessary delivery infrastructure.

Investment is needed along the whole value chain for hydrogen—building hydrogen production facilities, retrofitting existing facilities with CCUS,

[28] https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx
[29] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf
[30] https://onlinelibrary.wiley.com/doi/10.1002/ese3.956
[31] https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx
[32] https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction
[33] https://rmi.org/the-truth-about-hydrogen/
[34] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf
[35] https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html
[36] https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf
[37] https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf
[38] https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

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US$500bn
in forecasted Hydrogen investments through 2030

24%
of global energy demand can be met by hydrogen by 2050

investing in electrolysers and renewable electricity production, and building infrastructure for its storage, transport and distribution. The required investment is estimated at US$500 billion through 2030.[39] Industry joint ventures, public-private partnerships, and risk-mitigating financial instruments can facilitate such investments.[40]

The cost trajectory bodes well. The largest contributor to "green" hydrogen production costs are wind and solar power, which are 80% cheaper than in 2010. Electrolysis capacity is expected to be at least 55 times greater by 2025 compared to 2015, further driving down costs.[41]

Government action is necessary to scale up and improve the bankability of low-carbon hydrogen production. Carbon pricing is a vital part of the framework needed.[42] Commercial lenders may also need a framework where governments cover the price difference between "green" hydrogen and "grey" hydrogen.[43]

Government climate commitments are helping to drive massive investments in clean energy, including hydrogen. Globally, 359 large-scale hydrogen projects had been announced by July 2021—more than a third of them since February 2021.[44]

Europe is a leader in hydrogen development, accounting for more than 50% of announced projects and estimated investments of US$130 billion.[45] While focused on hydrogen broadly, the aim is an open and competitive EU hydrogen market by 2030, and increasing hydrogen's share in Europe's energy mix, from less than 2% today to 13-14% by 2050.[46] This will require major increases in Europe's renewable electricity production, with about 25% of renewable electricity capacity needed for clean hydrogen production by 2050.[47]

Building on this, the European Commission has introduced funding instruments like Important Projects of Common European Interest[48]—where EU member states jointly fund high-risk breakthrough innovation projects[49] and mechanisms that are part of the European Green Deal[50], including the EU Renewable Energy Financing Mechanism.[51] The European Investment Bank can boost projects located in high-risk countries, export credit insurers can help lower risk[52] and the European Clean Hydrogen Alliance aims to develop an investment agenda and build a concrete pipeline of clean hydrogen projects.[53]

39 https://www.straitstimes.com/singapore/environment/hope-for-green-future-also-rests-on-harnessing-hydrogen-trapping-carbon
40 https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-Scaling-up_Hydrogen-Council_2017.compressed.pdf
41 https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf
42 The mechanisms behind carbon pricing are explained later in the report.
43 https://www.siemens-energy.com/global/en/news/magazine/2021/financing-hydrogen-economy.html
44 https://hydrogencouncil.com/en/hydrogen-insights-updates-july2021/
45 https://hydrogencouncil.com/en/hydrogen-insights-updates-july2021/
46 https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
47 https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
48 https://ec.europa.eu/competition-policy/state-aid/legislation/modernisation/ipcei_en
49 https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226
50 https://ec.europa.eu/regional_policy/en/newsroom/news/2020/01/14-01-2020-financing-the-green-transition-the-european-green-deal-investment-plan-and-just-transition-mechanism
51 https://ec.europa.eu/info/news/european-green-deal-new-financing-mechanism-boost-renewable-energy-2020-sep-17_en
52 https://www.siemens-energy.com/global/en/news/magazine/2021/financing-hydrogen-economy.html
53 https://www.ech2a.eu/missionandvision

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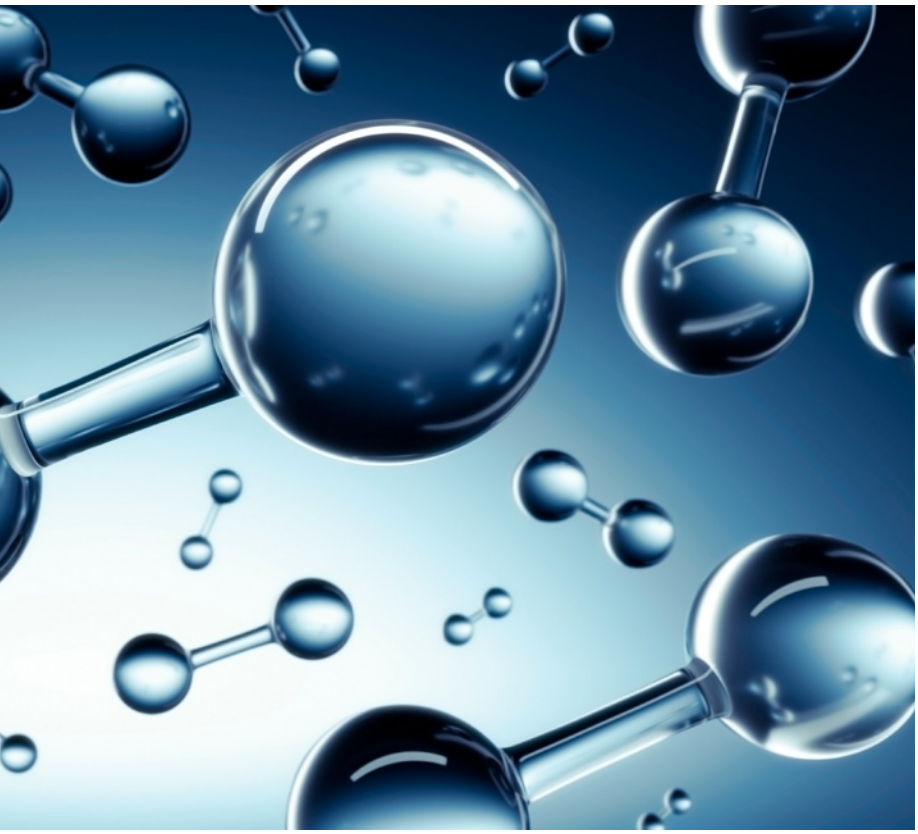

Trailing behind, China has set ambitious targets for hydrogen to comprise 10% of its energy mix by 2050, making available US$20 billion in public funding for hydrogen projects[54] including the approval of a recent green hydrogen mega-project.[55] The US government's Hydrogen Energy Earthshot[56] initiative, launched in June 2021, aims to slash the cost of low-carbon hydrogen—made from renewables, nuclear, and thermal conversion—by 80% within a decade. The initiative establishes a framework for clean-energy deployment, including support for demonstration projects.[57]

One of the world's biggest climate-neutral hydrogen refineries is being built in Chile with German government start-up financing on the capex side[58], including energy companies HIF, Siemens Energy, ENEL Green Power, and car manufacturer Porsche—which plans to use the fuel in its cars.[59] The pilot aims to supply 550 million litres of "green" hydrogen derivative annually by 2026—enough to fuel the cars of a million people.

[54] https://hydrogencouncil.com/en/hydrogen-insights-updates-july2021/
[55] https://www.bloomberg.com/news/articles/2021-08-18/china-approves-renewable-mega-project-focused-on-green-hydrogen
[56] https://www.energy.gov/articles/secretary-granholm-launches-hydrogen-energy-earthshot-accelerate-breakthroughs-toward-net
[57] https://www.energy.gov/articles/secretary-granholm-launches-hydrogen-energy-earthshot-accelerate-breakthroughs-toward-net
[58] https://www.siemens-energy.com/global/en/news/magazine/2021/financing-hydrogen-economy.html
[59] https://www.siemens-energy.com/global/en/news/magazine/2021/haru-oni.html

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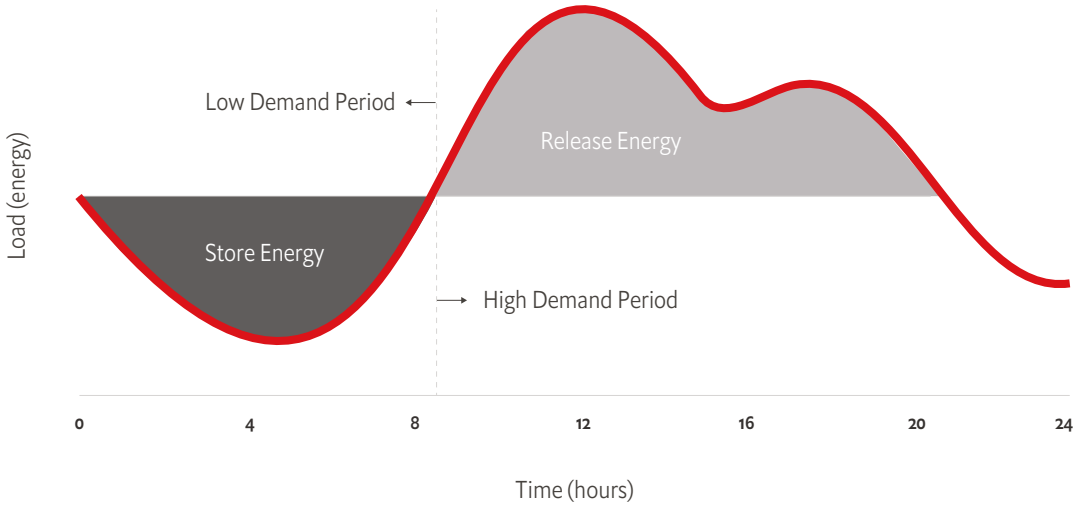
Grid-scale energy storage:

A key element in the transition to net-zero energy systems is grid-scale energy storage—a way of storing energy on a large scale within an electrical power grid. Electrical energy is stored during times when electricity supply is high (especially from intermittent power plants such as renewable electricity from wind, tidal and solar power) or when demand is low, and later returned to the grid when demand (and therefore price) is high.

Figure 4. Levelling the playing field
Daily energy storage and load levelling estimates



Source: Center for Sustainable Systems, University of Michigan, 2020

There are two well-established and commercialised energy storage technologies.

Pumped storage hydropower (PSH) accounts for over 94% of installed energy storage capacity.[60] PSH involves two water reservoirs at different elevations, one at a higher level and one lower. At times of low energy demand, water stored in the lower reservoir is pumped uphill using excess energy from solar and wind power. When demand is high, or solar and wind power is not sufficient, the upper reservoir releases water downhill through a generator, producing energy and making up the demand shortfall. PSH holds great potential as a clean and long-term energy storage solution as it does not produce any polluting by-products.[61]

[60] https://www.hydropower.org/factsheets/pumped-storage#:~:text=Pumped%20storage%20hydropower%20is%20the,(GWh)%20of%20electricity%20globally.
[61] https://www.energy.gov/eere/water/pumped-storage-hydropower

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However, PSH has its drawbacks. Its geographic requirements may limit scalability and application globally as it relies on specific environmental requirements. Owing to these requirements, these systems are plagued by high upfront capital costs.[62] PSH systems also interrupt river systems, which can result in adverse impacts on animal migration paths, issues with water quality, and human or wildlife displacement.[63]

Batteries are the other well-tested storage medium, currently deployed at utility-scale in Australia, Japan, the US and Europe.[64] Lithium-ion batteries in particular are efficient, convenient, reliable, and their use is rapidly expanding.[65] When not meeting peak demand, battery energy-storage systems can earn revenue by providing operating reserves for the transmission system operator.[66] However, they have two key drawbacks—the limited duration of their storage and their significant social and environmental impacts.[67] Batteries are made using various minerals, and their production can generate considerable amounts of environmental pollutants, including GHGs and hazardous waste.

Globally, lithium-ion chemistries dominate the current market for grid-scale battery storage.[68] The cost of a lithium-ion battery pack dropped from US$900/kWh in 2011 to less than US$140/kWh in 2020.[69] However, their market dominance could pose problems for grids.[70] Lithium-ion batteries are difficult to customise[71] moment-to-moment in ways most useful to the grid. They can also catch fire.[72]

Cost reductions in lithium-ion battery pack

US$900/kWh in 2011 → US$140/kWh in 2020

Alternatives being researched include fluorenone batteries[73]—made of a low-cost organic compound—and sodium-iodide batteries, which are safe and have longer lifespans.[74]

Regulatory and market barriers are obstacles to large-scale deployment of batteries.[75] Upfront costs are high, so governments can stimulate demand by subsidising battery storage owners.[76] Some regions still need to develop a regulatory definition of grid-scale storage and ownership.

Distributed energy-storage projects offer two main sources of revenue: capacity payments from the local utility, and payments for demand-charge management for on-site load.[77] Typically, distributed energy-storage systems financed by collateralised loans have exhibited an acceptable rate of return to lenders.[78] However, regulatory risks can constrain the remuneration of energy-storage services.

62 https://www.nrel.gov/docs/fy21osti/76097.pdf
63 https://www.energysage.com/about-clean-energy/hydropower/pros-cons-hydropower/
64 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf
65 https://www.sciencedirect.com/science/article/abs/pii/S1364032119300334
66 https://www.nrel.gov/docs/fy19osti/74426.pdf
67 https://www.sciencedirect.com/science/article/abs/pii/S1364032119300334
68 https://www.nrel.gov/docs/fy19osti/74426.pdf
69 https://www.energy.gov/articles/long-duration-energy-storage-support-grid-future
70 https://energy.mit.edu/publication/energy-storage-for-the-grid/
71 https://www.pnnl.gov/news-media/compound-commonly-found-candles-lights-way-grid-scale-energy-storage
72 https://www.sciencedaily.com/releases/2021/07/210721120651.htm
73 https://www.pnnl.gov/news-media/compound-commonly-found-candles-lights-way-grid-scale-energy-storage
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75 https://www.nrel.gov/docs/fy19osti/74426.pdf
76 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf
77 https://www.nortonrosefulbright.com/en-us/knowledge/publications/c93e1b30/financing-energy-storage-projects-assessing-risks---part-2
78 https://www.nortonrosefulbright.com/en-us/knowledge/publications/c93e1b30/financing-energy-storage-projects-assessing-risks---part-2

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Scaling up

Using more conventional renewables such as solar and wind alone is not sufficient to meet fluctuating energy demands while reducing reliance on non-intermittent fossil fuel power systems. Grid-scale energy storage systems can fill this gap but require sufficient investment to overcome high costs.

Despite the challenges facing energy storage projects, these systems are attracting funding from institutional investors such as insurance and pension funds as well as traditional banks. For example, at the beginning of 2021, CEP Energy, a renewable energy fund in Australia, announced the largest proposed grid-scale battery project in the world to date. Valued at US$2.4 billion, the project involves building four battery storage plants at different locations around Australia totalling 2,000 megawatt capacity. With new energy-storage technologies reaching demonstration stage, investors will be keeping a close eye on potential risks, such as exposure to penalties for non-delivery of power and potential revenue stream uncertainty.[79]

In addition to private investments, governments are playing a role in accelerating development and deployment of low-cost grid-scale energy storage. In March 2021, the US Department of Energy announced the construction of a US$75 million grid-scale energy storage research facility, the Grid Storage Launchpad (GSL). With the aim of completing construction in 2025, the GSL will have 30 research laboratories, including testing chambers for new grid-storage technologies.[80]

All in all, more innovation and policy harmonisation are needed to advance energy-storage technologies—improving their function, revenue options, and lowering their environmental impact—and to build appetite for investment.

[79] https://www.nortonrosefulbright.com/en-au/knowledge/publications/5318d7a6/scaling-up-energy-storage-in-the-uk#section6
[80] https://www.energy.gov/articles/long-duration-energy-storage-support-grid-future

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Advanced nuclear energy: high risk, high reward

The final set of technologies highlighted in this report—advanced nuclear technologies—can fall under two categories: small modular reactors (SMRs) and advanced modular reactors (AMRs). SMRs are based on the traditional light-water reactor design that uses slightly enriched uranium but can be developed on a smaller scale. Meanwhile, AMRs—which are newer and still under development—are reactors that use novel cooling systems or fuels such as molten salt, thorium and thorium combined with uranium.

Along with generating clean, low-carbon energy, these advanced nuclear technologies can be scaled up or down according to energy demands. Owing to their smaller size, SMRs can easily be used in sites that do not need large plants, including smaller electrical markets, isolated areas and sites with limited water and land.[81] SMRs can be built in a factory environment, reducing construction risk and making them less capital intensive.[82]

AMRs also provide the benefit of increased flexibility in delivering electricity to the grid. They have the potential to generate low-cost electricity while offering new applications, such as domestic or industrial heat provision, or facilitating the production of hydrogen. These new applications open new avenues for generating additional revenue and can contribute to economic growth.[83]

However, with these promises come some perils. Advanced nuclear technologies are still primarily in the demonstration phase and are not yet market ready, which can deter investors. They are also plagued by public opposition stemming from environmental and safety risks associated with traditional nuclear power. While nuclear disasters such as Chernobyl and Fukushima were catastrophic, nuclear energy overall is one of the least 'deadly' energy sources (see Figure 5). Death rates per terawatt-hour (TWh) of nuclear power are notably lower than those of fossil fuels but the disproportionate negative publicity surrounding nuclear is stifling progress, policy and investment.[84]

Overshadowing these is the cost. The overall perception in many markets is that advanced nuclear energy technologies are too expensive. For example, while technologies such as SMRs are less costly to build, they lose out on economies of scale. Larger traditional reactors are cheaper per megawatt despite having lower flexibility and fewer applications.[85] To make up for the lost economies of scale, SMRs must be manufactured by the thousands, which is not yet possible. Even as countries grow expertise in advanced nuclear technologies, these cost reductions are difficult to foresee: in the US and France, two countries with the highest number of nuclear plants, costs have not fallen with construction experience.

[81] https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf

[82] https://www.energy.gov/ne/benefits-small-modular-reactors-smrs#:~:text=SMRs%20provide%20simplicity%20of%20design,as%20demand%20for%20energy%20increases.

[83] https://www.gov.uk/government/publications/advanced-modular-reactor-amr-feasibility-and-development-project

[84] https://ourworldindata.org/safest-sources-of-energy; Nuclear has 0.07 deaths per TWh from accidents and air pollution, compared with 24.6 deaths for coal, 18.4 for oil and 2.8 for gas

[85] https://energypost.eu/small-modular-reactors-for-nuclear-power-hope-or-mirage/#:~:text=As%20the%20name%20suggests%2C%20SMRs,to%20cost%20less%20to%20build.&text=Larger%20reactors%20are%20cheaper%20on,scale%20linearly%20with%20generation%20capacity.

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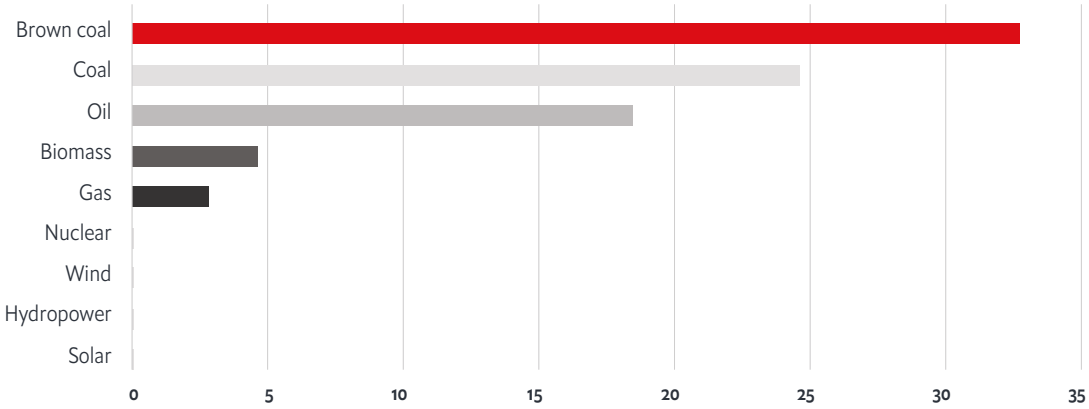
Figure 5. Death by power

Death rates from energy production, per terawatt-hour (TWh)



Source: Makandya & Wilkinson (2007), Sovacool et al. (2016), Our World In Data (2020).

80%
required increase in global nuclear power production by 2040

Despite these barriers, the road to net zero cannot bypass nuclear power. Germany's denuclearisation efforts are a clear example—research shows that since the nuclear phase-out that began post-Fukushima, Germany's emissions actually increased by 5% year-on-year between 2011 and 2017.[86] Such sentiment is echoed by a prominent advocate for nuclear energy, Bill Gates, who has stated that more nuclear power, including from advanced nuclear technologies, is essential in the net-zero energy equation.[87]

Building momentum

To meet clean electricity goals, global nuclear power production must be ramped up by 80% by 2040.[88] Reducing costs and improving the profitability of advanced nuclear technologies is crucial in achieving this target. Although nuclear energy has been around for some time, advanced nuclear is yet to reach the commercialisation stage. Economies of scale need to materialise—licensing regimes, reactor designs and standards harmonisation will be essential here.[89] Experts believe that the next 10 years are expected to be the demonstration period, with both government and private funding being a key driver. Only after this will deployment kick off.[90]

Globally, there are examples of companies making progress towards this with the support of government and private funding.

In the US, NuScale Power,[91] a company designing SMRs, has been funded by Fluor Corporation, a global engineering company, and the US government. TerraPower,[92] which is building nuclear capacity, was part-founded by Bill Gates. Both companies have access to a production tax credit and government loan-guarantee programme to access low-rate financing.

[86] https://haas.berkeley.edu/wp-content/uploads/WP304.pdf
[87] https://www.cnbc.com/2021/06/11/bill-gates-bullish-on-using-nuclear-power-to-fight-climate-change.html
[88] https://iea.blob.core.windows.net/assets/ad5a93ce-3a7f-461d-a441-8a05b7601887/Nuclear_Power_in_a_Clean_Energy_System.pdf
[89] https://www.oecd-nea.org/upload/docs/application/pdf/2020-07/7530-reducing-cost-nuclear-construction.pdf
[90] Interview with Dr Matt Bowen, research scholar at Columbia University's Center on Global Energy Policy
[91] https://www.nuscalepower.com/about-us
[92] https://www.terrapower.com/about/

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In the UK, Rolls-Royce is leading a consortium to build a fleet of 16 affordable SMR-based power plants.[93] Each reactor is expected to have a capacity of 470 megawatts, enough to power nearly 1.3 million homes.[94] The consortium has already secured over £200 million from the UK's national science and research funding agency, UK Research and Innovation (UKRI), and £300 million from industry partners.[95] The initiative aims to return £52 billion to the UK economy by 2050, generate a £250 billion export market and create up to 40,000 high-value jobs.

Terrestrial Energy, a Canadian company solely focused on developing next-generation nuclear technology, has designed the Integral Molten Salt Reactor, an AMR the company aims to have commercially licensed and operating in this decade. While the total figure is unclear, the company has secured notable private venture capital funding over the past five years.[96] It has also received public funding from the Canadian government, including a recent landmark US$20 million investment,[97] and the US Department of Energy.[98]

[93] https://www.rolls-royce.com/innovation/small-modular-reactors.aspx#section-programme-updates
[94] https://www.theguardian.com/business/2021/oct/15/uk-poised-to-confirm-funding-for-mini-nuclear-reactors-for-green-energy
[95] https://www.ukri.org/news/uk-government-invests-215-million-into-small-nuclear-reactors/
[96] https://www.terrestrialenergy.com/2016/01/26/nuclear-energy-insider-canada-edges-closer-smr-build-vc-funding-deal/; https://www.terrestrialenergy.com/2016/09/12/energy-collective-terrestrial-energy-lands-4m-new-round-funding/
[97] https://www.terrestrialenergy.com/2020/10/15/terrestrial-energy-receives-canadian-government-funding-for-imsr-generation-iv-nuclear-plant/
[98] https://www.terrestrialenergy.com/2016/06/27/manufacturer-ge-hitachi-lead-nuclear-research-project-doe-provides-82m-funding/

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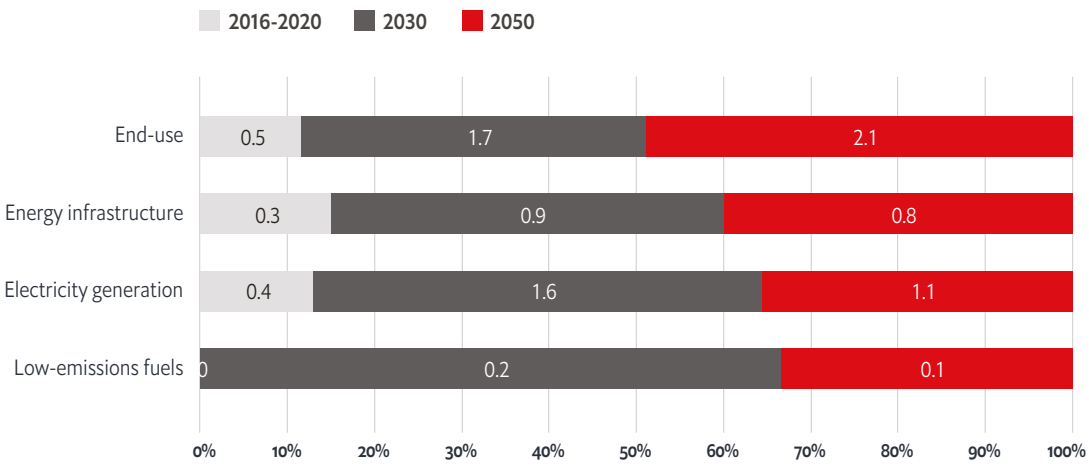
Financing the road to net zero

Clean-energy investment needs by 2030:
US$4trn /year

While this report has so far focused on four different technologies and approaches to net-zero energy systems, they all face a common barrier—inadequate investment. To reach net-zero emissions by 2050, clean-energy investment worldwide must triple by 2030 to around U$4 trillion a year.[99]

Net-zero energy systems need massive investments in new infrastructure (for production, transport and storage of energy from new sources, and captured or removed CO_2), and end-use products (boilers, vehicles, ships, etc). Many of the technologies discussed in this report face a 'chicken and egg' conundrum—investors are cautious to finance new infrastructure and products because of limited markets, but the only way to build these markets is by making the initial investment. Transitions throughout supply chains need to happen fast.

Figure 6. Ramping up
Clean-energy investment in the net-zero pathway, 2016-2050 (US$ trillion)



Source: International Energy Agency (IEA), 2021

[99] https://www.iea.org/reports/net-zero-by-2050

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Invesco perspective: Building for the future

Dr Henning Stein, Global Head of Thought Leadership

Brian Watson, Portfolio Manager, Invesco Real Estate

As investors, taking a high-level view for now, how should we think of the transition to clean energy?

Henning: As well as seeing it as an unprecedented growth opportunity, we should recognise it as an encapsulation of several hugely significant investment trends. It brings together long-term thinking, the rise of ESG—environmental, social and governance—considerations and the emergence of thematic investing.

Taking all these dynamics into account, we should also recognise that the transition is likely to transform almost every aspect of our lives. In addition, crucially, we should recognise that this transformation will be for the better.

This is a point that's sometimes overlooked. Tech-driven innovation and disruption are often perceived as making our lives easier or more amusing without improving them in the truest sense, but the transition to clean energy isn't about cosy convenience or mere entertainment – it's a matter of necessity and collective survival.

Both as investors and as citizens, we should acknowledge this as an instance of technological progress whose genuinely life-enhancing capacity is manifest. That's a vital component of the bigger picture.

And what do we find if we move beyond the bigger picture and adopt a much more granular view?

Brian: That's where the picture starts to become more complicated, of course. Once you start to peel back the layers, as in any investment arena, you see the complexities – and there are perhaps more in this sphere than in most.

Things aren't always black and white – or green and not green – when we look at some of the companies behind the emerging technologies in this space. But we shouldn't be especially surprised by this, given that the journey to net zero is still in its infancy.

Balancing the short term and the long term is also key here. For instance, it might be that the businesses forecast to have the most tremendous growth right now aren't those we would immediately think of as green.

By way of illustration, it's by no means certain that hydrogen or wind companies will make significant amounts of money in the near future – yet it's reasonably likely that some mining companies will. The road to net zero will present all kinds of twists and turns like this, and we'll need to negotiate them as best we can.

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Is it simply a case of being patient?

Henning: It's obviously a case of thinking for the long term, as I said earlier. We're literally building for the future here. At the same time, though, we shouldn't disregard the possibility of achieving the transition to net zero more quickly than envisaged if technology can enable us to do so.

As investors, we first need to identify the solutions that are most likely to be effective in bringing about the desired transformation. As we've seen, this demands substantial research, engagement and insight.

We then need to back these solutions with the capital they require to succeed – because if they don't get the support they deserve, if they're unable to realise their transformative potential, everyone is likely to lose out. That's the reality of the situation.

In doing all this, we may need to accept that the results we hope to see may not be immediately apparent. But we should also remember that this always has been, and always will be, the nature of long-term investing.

How might the shifting policy landscape affect your investment decisions?

Brian: The policy ecosystem will be a constant factor in our thinking. It's likely to be especially important with regard to the longer-term viability of investments versus their ability to provide short-term gains.

For example, it could be pretty nerve-wracking to make an investment that works only because of a particular incentive. That's why it's vital to look at the mathematics behind net-zero investments and home in on those that have less exposure to policy shifts.

It's also why direct engagement is such a powerful weapon in a responsible investor's arsenal. It's not enough simply to scratch the surface when we engage with companies on these matters – we have to dig as deep as possible and ask the right questions.

The bottom line is that we need to be sure the companies we invest in are genuinely capable of contributing to the transition to clean energy over the longer term. This is really a crystallisation of what asset management in the 21st century is all about – mitigating risk, generating returns and allocating capital as productively as possible.

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Government funding

Governments play a vital role in de-risking the roll-out of net-zero infrastructure assets.[100] This is because investors face three main risks: limited track records of immature technologies, unproven revenue models, and risks of future changes in regulations or government policy that could affect the returns on investment.

There are precedents, however, such as the development of offshore wind power in the UK. From the start, there was dialogue between key market players and government actors about which policies were needed to give investors confidence. The dialogue culminated in a sector deal where the government committed to a programme of policy support and consistent legislation, and industry actors committed to investment objectives. Offshore wind was initially heavily subsidised by the government. The government set an administrative price per unit of power and its investment ultimately created jobs and a market while contributing to clean energy.[101]

The rate of acceleration in CCUS deployment needed over the next decade is a major challenge,[102] but here too there is a precedent in the rapid deployment of a similar technology—flue gas desulphurisation, which removes toxic sulphur dioxide emissions in power stations and industrial plants. The technology was pioneered in the UK in 1933, but not deployed until governments introduced strong regulatory and policy support.[103] The US, for example, rolled it out in the 1970s following legislation mandating emissions reductions regardless of economic or technical feasibility. The UK followed suit in the 1980s. As history dictates, the role of governments is essential in deploying innovative clean-energy systems.

Carbon pricing

Since climate change is widely seen as a market failure, there is a need to overcome this in economic terms. A carbon price is a cost applied to carbon emissions that incentivises the cutting of these emissions. There are two mainstream government implementation mechanisms—a carbon tax on the distribution, sale or use of fossil fuels, and a cap-and-trade system. The former increases the cost of polluting fuels and associated end-products and services, thereby incentivising businesses and individuals to adopt less carbon-intensive production and consumption models. The latter involves a government 'capping' the total allowable emissions in a country, requiring businesses to purchase or be allocated specific permits to pollute (see Figure 7). Such permits can be traded with other companies, introducing a market for pollution while limiting the overall level of emissions.

[100] https://www.pwc.com/jg/en/events/document/pwc-unlocking-capital-for-net-zero-infrastructure.pdf
[101] Huub den Rooijen, Managing Director, Marine, at The Crown Estate (UK) speaking at the 2021 World Ocean Summit: Energy: What is required to maximise the potential of offshore wind? (NB – he was Director of energy, minerals and infrastructure, when he was speaking at the WOS) https://economist.app.swapcard.com/event/world-ocean-summit-virtual-week/planning/UGxhbm5pbmdfMzQ4NzI4
[102] https://www.iea.org/reports/ccus-in-clean-energy-transitions/accelerating-deployment
[103] https://transform.iema.net/article/fgd-ccs

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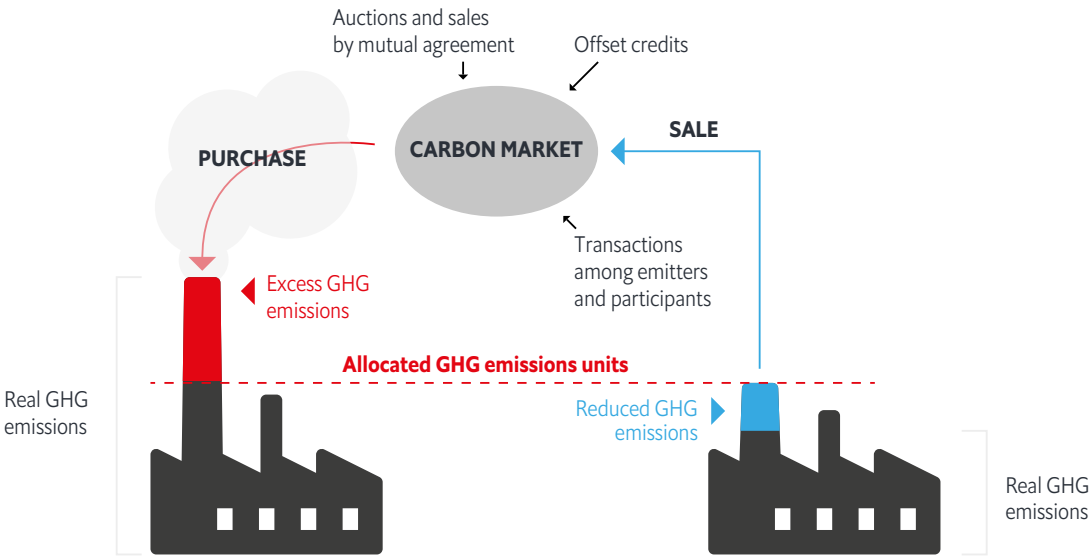
Figure 7. The carbon trade-off
The carbon emission cap-and-trade system explained



Source: Land Trust Alliance (2021).

Carbon pricing, which uncovers the hidden cost of emissions, covers 20% of GHG emissions.[104] In 2020, carbon pricing instruments generated US$53 billion in revenue, US$8 billion more than in 2019, mainly because of a rise in the EU allowance price.[105] The High-Level Commission on Carbon Prices suggests that prices need to be in the range of US$40–80/t$CO_2$e in 2020 and US$50–100/tCO_2e by 2030 to achieve the temperature goal of the Paris Agreement.[106] In 2019, almost 50% of emissions were still priced below US$10/t$CO_2$e, but prices are rising in regions like Europe where policy frameworks for curbing emissions are strengthening.[107]

Several countries have launched national emissions trading systems (ETS) this year, including China whose ETS is the world's largest carbon market, covering 30% of its emissions.[108] At the sub-national level, California has one of the highest carbon prices in the world in the form of its Low Carbon Fuel Standard[109]—a market-based mechanism that trades decarbonisation of transportation fuels, currently trading at about US$200/t$CO_2$e.

[104] https://www.carbonpricingleadership.org/who
[105] https://openknowledge.worldbank.org/handle/10986/35620
[106] https://openknowledge.worldbank.org/bitstream/handle/10986/32419/141917.pdf?sequence=4&isAllowed=y
[107] https://www.ft.com/content/2b965427-4fbc-4f2a-a14f-3be6019f0a7c
[108] https://openknowledge.worldbank.org/handle/10986/35620
[109] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

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The private sector is also using internal carbon pricing to identify opportunities to mitigate and reduce climate-related financial risks. Financial institutions, including banks, are using carbon pricing to review credit applications, assess their own portfolio footprint and inform investment decisions to manage climate-related risks and opportunities.[110]

Financial instruments

Examples of public financial instruments to mobilise funds include the World Bank's Pilot Auction Facility, and the UK's Contracts for Difference programme, which supports renewable energy deployment. Auctioned price floors[111]—subsidies that offer a guaranteed price for future emission reductions—maximise climate impact per public dollar while incentivising private investment in low-carbon technologies. Institutional grants and concessional loans (e.g., from the World Bank and the Green Climate Fund) are insufficient to provide the price signals required to shift private investments towards low-carbon alternatives at scale.

The role of credit markets in the path to net-zero energy cannot be overlooked. Green bonds can help to enable immediate investment in climate-change mitigation and would be repaid by future generations.[112] When combined with carbon pricing, their performance is further improved. The current market for green and sustainable bonds stands at US$1.5 trillion, which has opened up fixed-income opportunities.[113]

An explicit net-zero target for finance[114]—to complement an existing focus on climate risk—could help increase financial flows. The UK, for example, is considering making net-zero targets and plans mandatory for financial institutions.[115]

Several finance sector initiatives have launched recently, including the Sustainable Markets Initiative's Insurance Taskforce and Financial Services Taskforce.[116] The latter launched the Net-Zero Banking Alliance (NZBA) in April 2021, hosted by the United Nations Environment Programme Finance Initiative (UNEP FI), which convenes 55 of the world's leading banks to support the implementation and deployment of decarbonisation initiatives.[117] Also in April, Mark Carney and the 26th United Nations Climate Change Conference (COP26) Private Finance Hub[118] launched the Glasgow Financial Alliance for Net Zero (GFANZ), bringing together over 160 firms responsible for combined assets in excess of US$70 trillion, including Allianz, Axa, Zurich, BlackRock, Fidelity and Vanguard.

While government funding and public financial instruments play a vital role in financing and promoting investment in net-zero energy systems, other financing models and mechanisms[119] are needed for different stages of development.

[110] https://www.carbonpricingleadership.org/who
[111] https://www.tandfonline.com/doi/full/10.1080/14693062.2017.1389687
[112] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3440367
[113] https://blog.pimco.com/en/2021/07/the-race-to-net-zero-challenges-and-opportunities
[114] https://www.theccc.org.uk/wp-content/uploads/2020/12/Finance-Advisory-Group-Report-The-Road-to-Net-Zero-Finance.pdf
[115] https://www.theccc.org.uk/wp-content/uploads/2020/12/Finance-Advisory-Group-Report-The-Road-to-Net-Zero-Finance.pdf
[116] https://www.sustainable-markets.org/taskforces/financial-services-taskforce/
[117] https://www.unepfi.org/net-zero-banking/
[118] https://unfccc.int/news/new-financial-alliance-for-net-zero-emissions-launches
[119] https://www.sciencedirect.com/science/article/abs/pii/S2352152X18300355

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Venture capital investment

Venture capital (VC) for start-up companies and small businesses is expected to have long-term growth potential. VC can play a vital role in the rapid commercialisation of proven technologies. This form of investment in the climate tech sector—which includes energy and carbon-removal technologies—increased from US$418 million a year in 2013 to US$16.3 billion in 2019.[120] However, this still represents just 6% of total capital invested in 2019. While such investment can spur innovation in clean energy that otherwise may not have been possible, it may not offer investors lucrative financial returns.[121] VC funding is also skewed geographically—half of VC funding in 2019 went to companies in the US and Canada, followed by China and Europe, while other regions and emerging markets attracted very little investment.

Traditionally, technologies that need significant capital investment over long periods of time struggle to attract VC. Carbon-capture projects, for example, have attracted relatively little—VC-backed carbon capture start-ups took in US$336.5 million last year, much of it driven by oil companies, governments and other non-traditional investors.[122] Nevertheless, this figure has risen each year since 2017, showing the potential of VC funding.[123] Companies investing in CCUS include Equinor Ventures,[124] which invested in modular carbon capture company, Carbon Clean.[125] VC Fuel LLC—a VC firm focused exclusively on energy transition—also invests in CCUS, as well as clean hydrogen.[126]

Similarly, HydrogenOne Capital is the world's first clean hydrogen-focused investment fund. With the aim of providing investors with clean hydrogen and energy storage investment opportunities, the fund raised over £100 million after its launch in July 2021.

An interesting example in this space is Nucleation Capital,[127] a VC fund focused on investing in early and mid-stage ventures developing advanced nuclear technologies as well as deep decarbonisation and grid optimisation ventures. Other examples include Amazon's Climate Pledge Fund,[128] and Microsoft's US$1 billion Climate Innovation Fund to accelerate development and deployment of new climate innovations through equity and debt capital.[129] In 2016, Hyundai Motor Company and the Beijing-Tsinghua Industrial R&D Institute set up a Hydrogen Energy Fund,[130] which aims to raise US$100 million from VC firms to foster growth of innovative hydrogen technology start-ups.

Some of the world's largest fossil fuel companies have also taken this step. For example, Saudi Aramco Energy Ventures which, despite most investments focusing on traditional oil and gas companies, is financing clean-energy companies, such as Form Energy, which is developing cost-

[120] https://www.pwc.com/gx/en/services/sustainability/assets/pwc-the-state-of-climate-tech-2020.pdf
[121] https://www.sciencedirect.com/science/article/pii/S0959652621005357
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effective, multi-day energy storage systems,[131] and Utility, which has as its core mission the production of low-carbon, low-cost hydrogen.[132] Other corporate funds stemming from legacy fossil fuel companies include BP Ventures, which has multiple investments in CCUS solutions, and Shell GameChanger, which is focusing on energy-storage technologies.

Crowdfunding

A less explored but budding source of investment in clean energy is crowdfunding. Crowdfunding sites allow individuals anywhere in the world to invest in start-ups and projects. While some sites only admit accredited investors with high incomes or assets, others allow individuals to invest US$100 or less. Crowdfunding has the potential to support start-ups in regions that do not attract much venture capital and have less access to traditional financial institutions, such as Africa, which saw 118% growth in overall crowdfunding value between 2015 and 2016 alone.[133]

This year, Proton Technologies Canada began a crowdfunding campaign on the Wayblaze platform for its clean hydrogen business[134] and, in 2020, German company Enapter launched a crowdfunding campaign to help develop mass production of its decentralised hydrogen generators (electrolysers).[135]

A major 12-megawatt battery energy-storage project in the Netherlands—run by GIGA Storage—raised €3.6 million[136] through the DuurzaamInvesteren ('Sustainable investing') platform.

Crowdfunding has even been used for nuclear technologies. In 2019, Moltex Energy raised £6 million through Shadow Foundr.[137] The company said it turned to crowdfunding because VC and private equity firms prefer quick returns that were difficult to get from new-generation nuclear plants that are possibly 10 years from operation.[138]

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Invesco perspective: The age of energy-tech

Dr Henning Stein, Global Head of Thought Leadership

Maynard Xu, Senior Credit Analyst, Invesco Fixed Income

How does the likely pace of change influence your thinking when you consider investments in the energy sector?

Henning: It's increasingly important to recognise we're entering the age of EnergyTech. We can no longer think of energy and technology as distinct sectors because today's truly cutting-edge energy companies are tech companies. It's the tech-driven transformation of the energy sector where the biggest opportunities are likely to lie.

Innovative businesses such as Tesla have ushered in this new era by redefining what an energy company should be. As a result, we can expect advances in energy-tech to become ever more radical during the years and decades ahead.

We can also expect a further wave of similarly innovative companies to follow the trailblazers, just as they followed pioneers such as Amazon and Salesforce in transforming other sectors. And a key challenge for investors as this journey unfolds will be to identify not just the architects of the energy revolution but also its enablers.

The extent of technological disruption is likely to be unprecedented, and we know disruption always brings losers as well as winners. This means companies that fall behind the curve are likely to exit the market, but it also suggests the emergence of investment opportunities on a scale never before witnessed.

How does this thinking translate to the fixed income arena?

Maynard: We always look at long-term viability when we assess a business investment. It's important to look across the full horizon, not just the next five years. For example, a company might have a stable revenue for seven years because it's paid through a contractor agreement by the national grid, but it won't be able to refinance a five-year bond if it doesn't have a business model in 10 years' time.

This is why stranded assets are such a big topic. Governments are increasingly putting pressure on companies, both directly and indirectly, to significantly step up their efforts to cut emissions. For example, a Dutch court recently ordered Shell to double their carbon emission reduction over the next 10 years (although the company is currently appealing the ruling). The question remains, however: how will they do that?

Selling these polluting assets to new owners in emerging markets won't solve the global emissions problem, yet these companies will lose out financially if they don't sell. Compensation is therefore needed to resolve this tension and ensure a genuine impact on emissions reductions.

From our perspective, we're increasing screening requirements and imposing stricter criteria when we're investing in companies. This means, for example, that those businesses not contributing to the carbon-reduction goal have higher financial costs.

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What are the main potential hurdles to a successful energy transition?

Henning: I would particularly emphasise four Cs: cost, controversy, complacency and complexity. The first two are closely related, and if the first can be negated then the second becomes redundant.

There's mounting evidence that the cost of clean energy is falling. The plunging cost of lithium-ion battery power per kilowatt-hour of energy offers arguably the most compelling illustration, while photovoltaic cells are already cheaper than new coal/gas-powered plants in most countries.

In turn, these failing costs are rendering clean energy less controversial. This is a big part of why multiple key stakeholders – governments foremost among them – are now embracing the transition to an apparently irreversible extent.

Complacency is the would-be elephant in the room. As we make progress, irrespective of how impressive it might be, we mustn't fall into the trap of believing we've ticked all the boxes and the job is done. If we can avoid that pitfall, at least in my opinion, this transition will be unstoppable – although the fourth C, complexity, will remain a long-term challenge.

What about the issue of greenwashing?

Maynard: There are numerous examples of corporates employing greenwashing tactics rather than making genuine contributions to the pathway to net zero. Unfortunately, this is still a widespread problem.

These are companies that "talk the talk" but don't "walk the walk" – which is to say they give themselves a green badge but do nothing to actually earn it. They present a picture of sustainability to the wider world, but if you dig deeper – as asset managers must – you find nothing beneath the surface.

This is why the investor community has to define a clear framework for assessing ESG. We need to tighten the rules to incentivise genuine changes in ESG behaviour. This is already happening, and now we have to make sure we keep building on progress.

Ultimately, it's vital to acknowledge that the route to a sustainable future will be complicated. We're going to encounter a lot of challenges, and it would be wrong to pretend otherwise. Overall, though, we believe the current direction of travel is encouraging.

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Looking to the future

As explored within this report, there is an abundance of examples of net-zero energy projects and initiatives by both public and private stakeholders that have successfully moved from concept to demonstration stage and are swiftly making strides towards commercialisation. The investment opportunity is immense but there remain complexities to overcome in the road to net zero. The crucial factor behind commercial success lies in investment. To bolster investor confidence and foster the required 300% increase in clean-energy investment in less than 10 years, incentives and cost reductions are required across the board.

With about 30% of the required additional investment expected to come from public sources and the remaining 70% from private, there is a need for multi-stakeholder cooperation involving technology developers, VC and private investors, and government actors. In the build-up to COP26, it is inevitable that governments will become even more ambitious with their commitments. Such ambition will likely drive further private sector investment, catalysing change and zeroing in on a net-zero future.

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