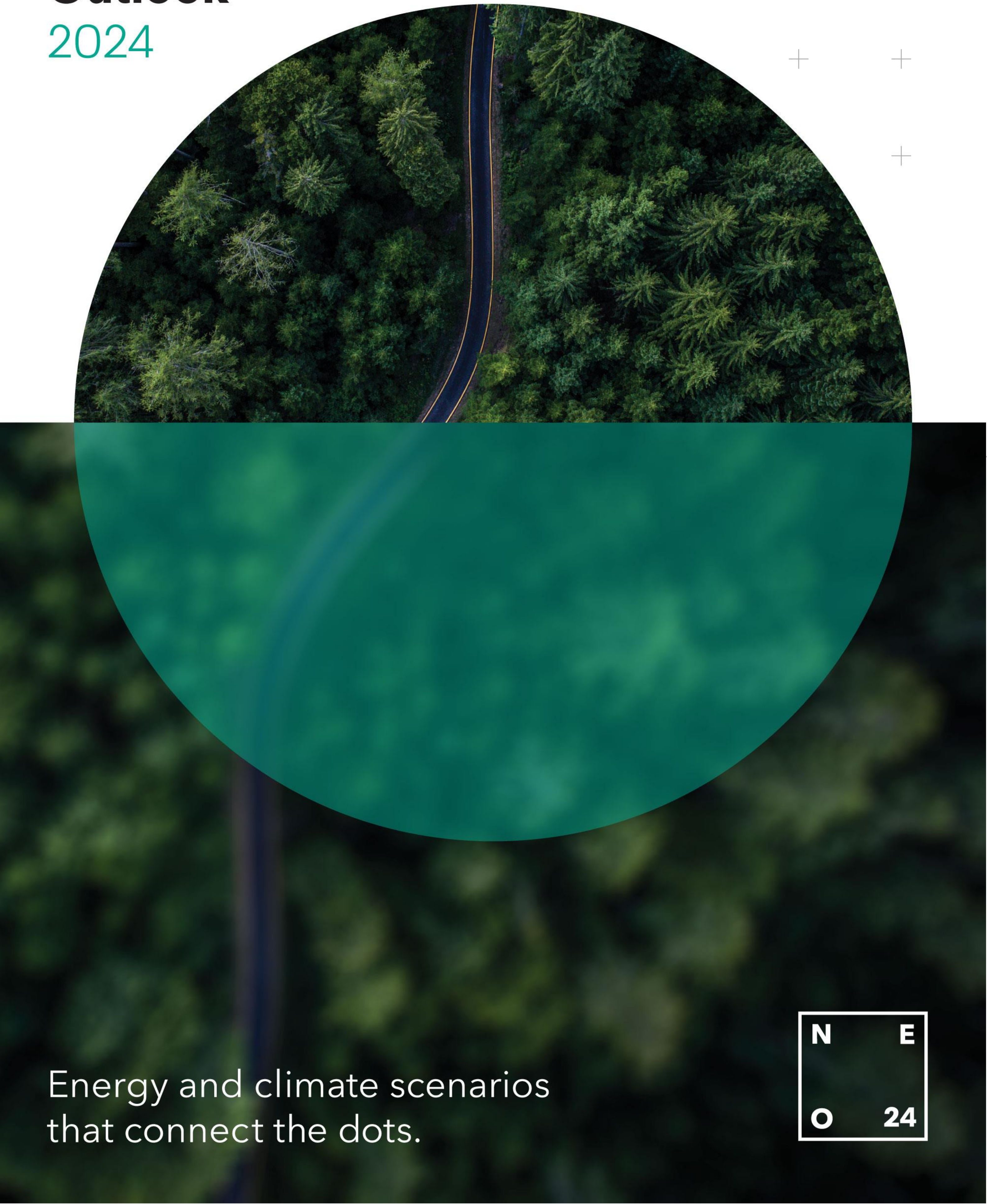
BloombergNEF

# New Energy Outlook 2024



Energy and climate scenarios that connect the dots.

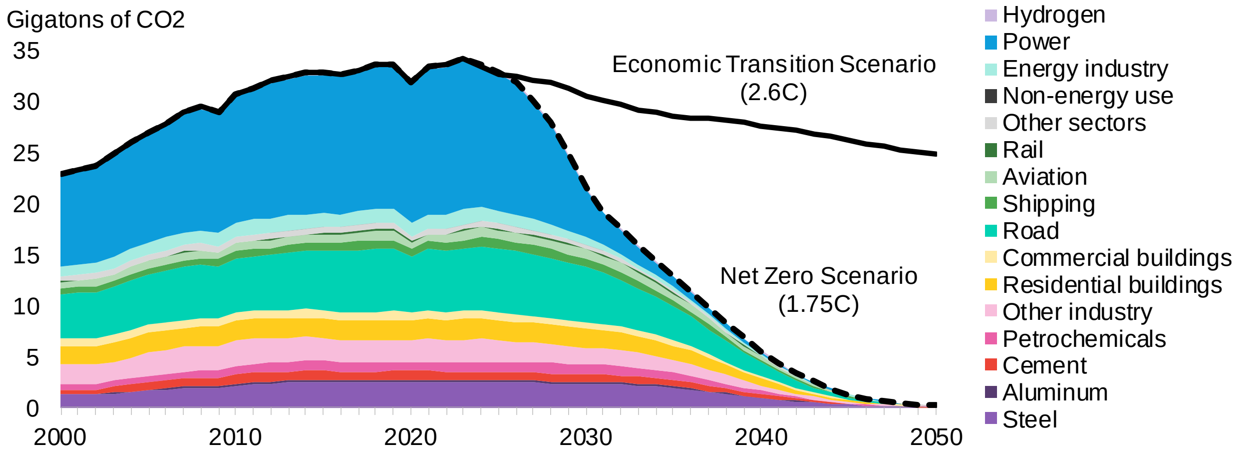
NEO 24

# Executive Summary

The window to reach net-zero emissions by 2050 is rapidly closing but there is still time for the world to get on track – if decisive action is taken now. Failure to do so risks putting even a 1.75C global warming target out of reach. Progress has been made. The energy transition has accelerated in recent years with the pace of clean technology deployment and capital investment surging to record levels. And while emissions remain stubbornly high despite that momentum, with an even faster ramp-up of everything from renewables to green fuels, BNEF sees carbon neutrality by mid-century as a tough but achievable stretch.

- The halfway point has now been reached in a make-or-break decade. Aligning with a net-zero trajectory will require an immediate peaking of emissions and fossil-fuel use across the global energy system – spanning the power, transport, industrial and buildings sectors.
- Cleaner power generation can drive the bulk of the aggressive emissions cuts needed this side of 2030, enabling more time to tackle 'hard-to-abate' areas like steelmaking and aviation, where cost-competitive low-carbon solutions have yet to scale. A net-zero pathway hinges on renewables capacity tripling between now and the end of the decade.
- None of this will be possible without accelerated spending. On the energy supply side, for every dollar that goes to fossil fuels, an average of $3 needs to be invested in low-carbon energy over the remainder of the decade – up from parity today. A fully decarbonized global energy system by 2050 could come with a $215 trillion price tag – not an insignificant amount, but only 19% more than in an economics-driven transition, where the Paris Agreement goals are missed and global warming reaches 2.6C.
- Regardless of whether the world heads for net zero or it ultimately proves a stretch too far, the era of fossil fuels' dominance is coming to an end. Even if the transition is propelled by economics alone, with no further policy drivers to help, renewables could still cross a 50% share of electricity generation at the end of this decade.

**Figure 1: Energy-related emissions and net-zero carbon budget, Economic Transition Scenario and Net Zero Scenario**




*Source: BloombergNEF*

This year's *New Energy Outlook* presents two scenarios that connect the dots between sectors, countries and technologies to map out how the transition could proceed from here. Our Net Zero Scenario charts country-level and global pathways to net zero by 2050, meeting the goals of the Paris Agreement. Meanwhile, our Economic Transition Scenario shows how the transition could unfold solely based on economic forces and technology tipping points that push the balance in favor of low-carbon technologies, without further policy action.

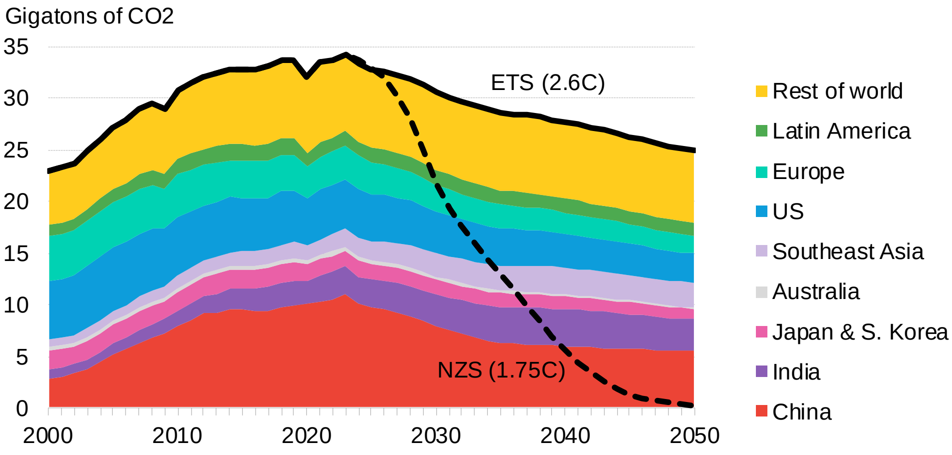
## Economic Transition Scenario

The Economic Transition Scenario (ETS) reflects a world where policymakers pursue an energy transition relying only on historical efficiency trends and economically competitive, commercially at-scale clean energy technologies. These measures alone see global emissions fall by 27% from current levels by 2050 and halve them versus a counterfactual 'no-transition' scenario in which there is no further progress on decarbonization.

The ETS requires no further support for clean technologies beyond existing measures, although it does hinge on a level playing field that allows these solutions to access markets and compete with incumbent technologies. This sets the stage for global renewables capacity to more than double by 2030 and quadruple by 2050, from current levels. With that growth, fossil fuels are toppled as the dominant source of electricity generation as renewables cross a 50% share of supply at the end of this decade.

Under the ETS, the increase in global temperatures above pre-industrial levels reaches 2.6C by 2100, with a 67% confidence interval.

**Figure 2: CO2 emissions by region and global temperature increase versus pre-industrial levels, Economic Transition Scenario and Net Zero Scenario**




*Source: BloombergNEF. Note: ETS is Economic Transition Scenario, NZS is Net Zero Scenario.*

### A cleaner, more efficient energy system

Both our scenarios describe a world where energy demand keeps climbing as economic growth continues and living standards rise around the world. The amount of energy delivered for end-use applications in the ETS increases by 34% to 2050, although the primary energy needed as input barely grows at all, thanks to the inherent efficiency gains associated with clean electricity-based technologies.

Generally, developed countries see their emissions decline between now and 2030 in the ETS. The availability and affordability of renewable energy and electric vehicles, coupled with modest power demand growth, mean these regions deploy clean energy technologies faster than any rise in energy demand in the short term. In contrast, developing economies such as India, Indonesia and Vietnam see their emissions rise in the ETS until the late 2030s, as their growing energy needs outpace the speed of clean energy deployment in the short term.

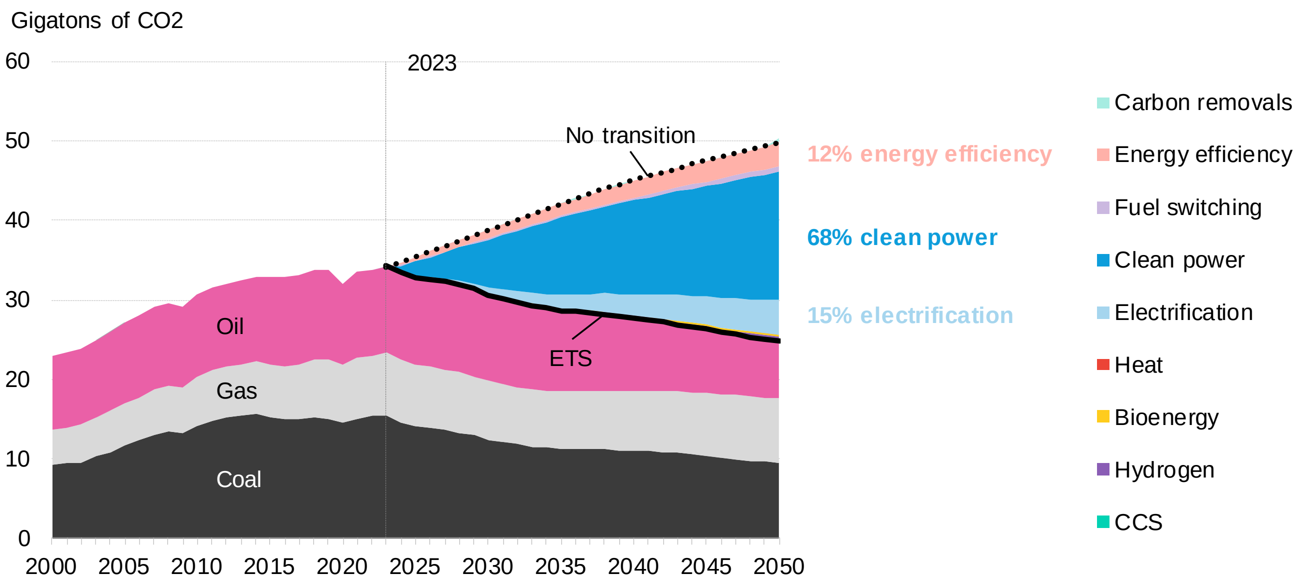
Strikingly, China's path follows the developed economy camp, with emissions falling immediately from 2024 through to the end of our outlook. The country's strong track record of clean-tech deployment demonstrates that it could immediately peak emissions under an economics-led transition.

## Renewables and electrification dominate an economic transition

Clean power is responsible for two-thirds of emissions reductions over 2024-2050 in the ETS, compared to a no-transition scenario in which there is no further progress on decarbonization (Figure 3). Wind, solar and nuclear start to displace existing fossil-fuel generation in the power system and meet new power demand.

The second-biggest driver is electrification of end uses such as EVs, heap pumps in buildings, and industrial processes, which abate 15% of emissions. Another 12% comes from energy efficiency improvements, including demand-side efficiency gains in households, buildings and more recycling in industry.

**Figure 3: $CO_2$ emissions reductions from fuel combustion by measure, Economic Transition Scenario versus no transition scenario**



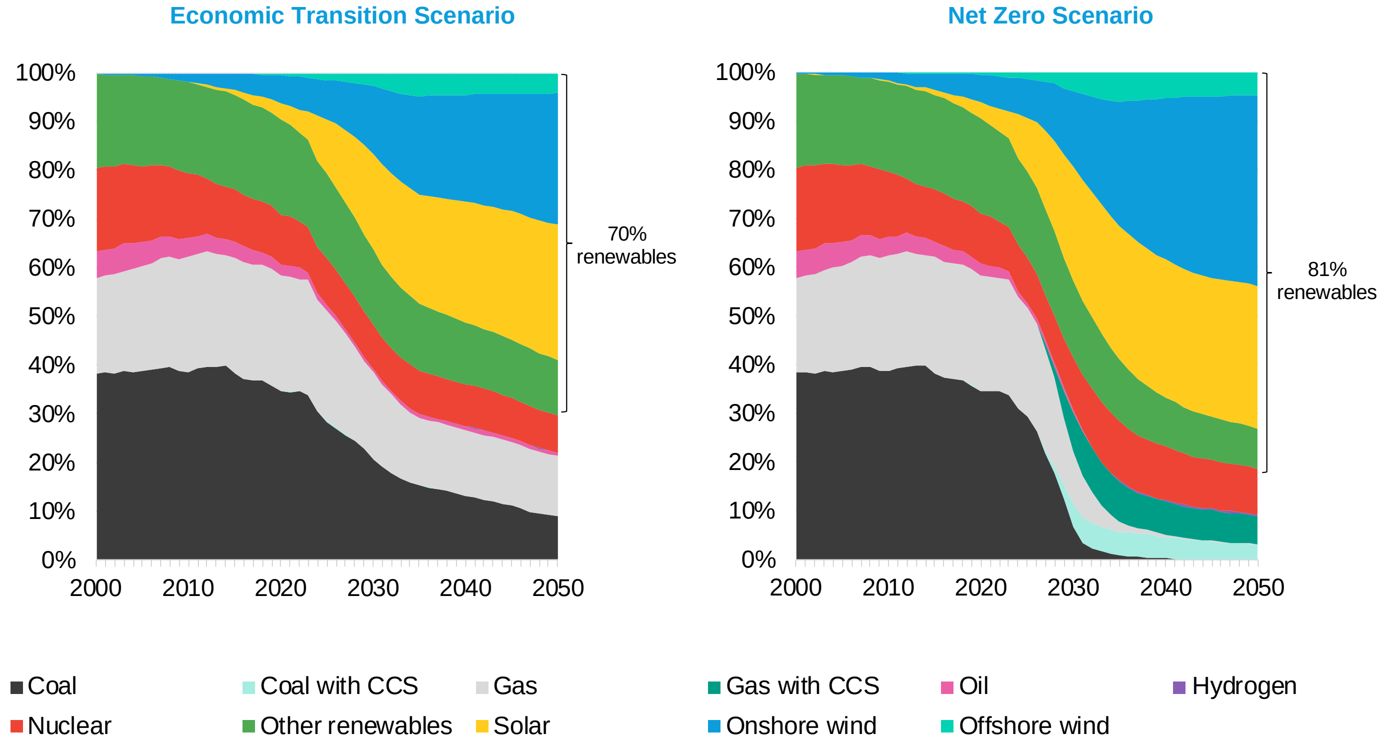

*Source: BloombergNEF. Note: ETS is the Economic Transition Scenario. The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes the future fuel mix does not evolve from 2023 (2027 for shipping). 'Clean power' includes renewables and nuclear, and excludes carbon capture and storage (CCS), hydrogen and bioenergy, which are allocated to their respective categories. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry.*

Global electricity demand in the ETS grows by over 70% from 2023 to just over 43,000 terawatt-hours in 2050. To supply this growing demand, the power system is increasingly built around cheap and abundant renewables.

Globally, generation from unabated fossil fuels in the ETS is down 22% by 2030 versus current levels, and 39% by 2050. This comes as coal generation recedes based on economics and phase-out schedules. Installed renewables capacity more than doubles by the end of this decade, driven by strong deployment in almost all markets. Meanwhile, installed nuclear capacity increases by almost a third by 2050.

The growth in renewables and stationary battery storage brings the era of fossil fuels as the predominant source of electricity generation to an end. Renewables overtake fossil fuels to reach 51% of power supply in 2030, 63% in 2040 and 70% in 2050 (Figure 4).

**Figure 4: Electricity generation by technology/fuel, Economic Transition Scenario and Net Zero Scenario**




*Source: BloombergNEF. Note: Includes electricity generation for hydrogen production under the Net Zero Scenario. 'Other renewables' includes all other non-combustible renewable energy, including hydro, bioenergy, geothermal and solar thermal. CCS is carbon capture and storage.*

The share of renewables is only a little higher by 2050 in the Net Zero Scenario, at 81%, albeit in a much larger system. But there are major differences across the rest of the generation mix. The share of nuclear in the Net Zero Scenario is 9% by 2050, while fossil fuels paired with CCS make up 9% of generation. Hydrogen-fired generation only accounts for under 1% globally on account of its high cost.

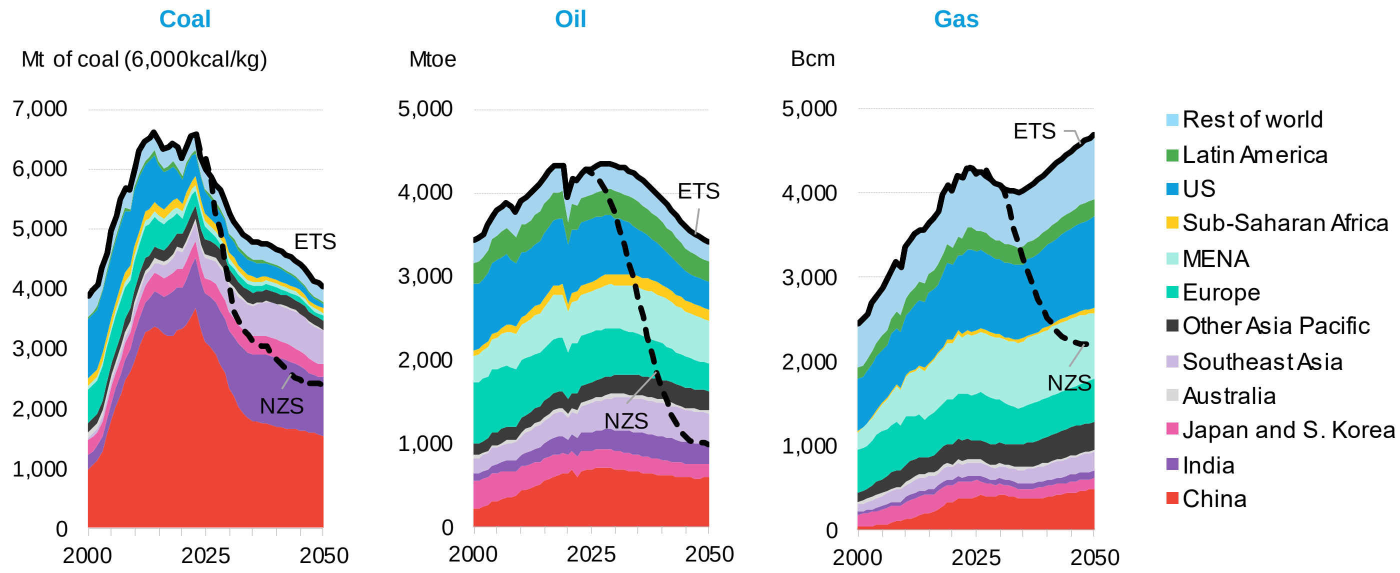
## Coal and oil demand enters a period of structural decline

Fossil fuels do not go away in our base case ETS, but coal and oil demand are in structural decline (Figure 5). Global coal demand peaks immediately, driven by falling demand in top consumer China. Renewables and coal-to-gas switching are increasingly displacing uncompetitive coal in the power sector, particularly in Asia Pacific.

Oil demand hits its highest point in 2028-29, propelled by demand destruction from electrification in road transport. By 2050, demand for both coal and oil is back to where it was in the early 2000s.

Natural gas demand plateaus in 2023-25 in the ETS, at about 4,300 billion cubic meters, marking the end of nearly two decades of uninterrupted growth. Demand then declines moderately until the mid-2030s before rising again to end up 9% higher in 2050 than today. Most new gas consumption comes from industry, particularly chemicals production. Global gas demand from the power sector declines by about 19% from current levels.

**Figure 5: Fossil-fuel demand by region, Economic Transition Scenario**




*Source: BloombergNEF. Note: ETS is Economic Transition Scenario; NZS is Net Zero Scenario. Mt is million metric tons. Mtoe is million tons of oil equivalent. Bcm is billion cubic meters. MENA is Middle East and North Africa.*

## System flexibility comes from both the demand and supply side

A power system based around variable wind and solar generation cannot work without significant sources of flexibility. This goes beyond simply adding more batteries to store excess electricity and discharge it when needed. Instead, flexibility needs to be an entire system solution that activates both supply and demand – a combination of demand response, increased interconnection, flexible 'peaker' plants, pumped storage, and smart EV charging (Figure 6). These are integrated by means of an extensive grid and managed using the latest digital technologies.[1]

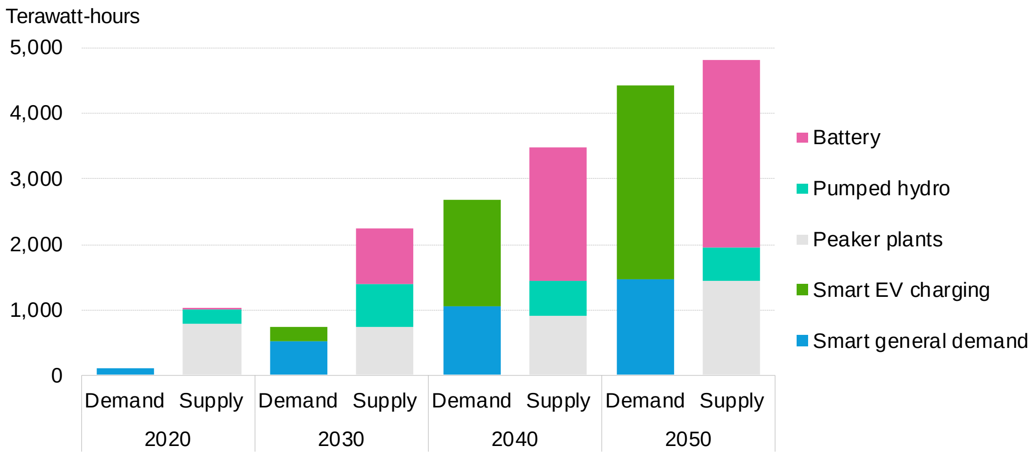
The most substantial sources of flexibility in the ETS are batteries and smart EV charging, which shift about 2,900 and 3,000 terawatt-hours of energy in 2050, respectively. This is a significant contribution, equivalent to 12% of overall demand being deferred or shifted combined across the

[1] Demand response is a grid-balancing mechanism whereby consumers are encouraged to shift their demand to times of higher electricity supply or low demand, typically through a financial incentive. A peaker plant is called upon when there is high demand for electricity, in order to help balance the grid.

two. Gas peaking plants and general smart demand also play important roles, shifting around 3% of electricity demand apiece in 2050.

Enabling this flexibility will require a corresponding buildout of the grid for both distribution and transmission, and clear price signals in the market to incentivize both demand and supply responses.

**Figure 6: Power system flexibility sources, Economic Transition Scenario**




*Source: BloombergNEF. Note: Peaker plants includes flexible thermal plants using abated and unabated fossil fuels or hydrogen. Smart general demand includes flexibility provided by consumers via smart appliances and other demand-side response. BNEF has not modeled flexibility from space heating, which will play a role in providing additional demand-side flexibility.*

### Without subsidies, there will be no industrial decarbonization

Unlike the power and transport sectors, where net-zero options can compete with conventional technologies, there are no fully decarbonized production routes for industry that are cheaper than unabated production. That makes either subsidies, or some form of carbon pricing, crucial to seeing any emissions reductions in industry based on economics. Where we have incorporated existing policy into our levelized costs, there is a small impact on industrial emissions, but widespread industrial decarbonization is otherwise absent in the ETS.

Green electricity can be competitive in electrified processes, but even with existing policies and subsidies there are only small changes to industrial emissions. Direct CO2 emissions (known as Scope 1) increase 6% from today to 2050, peaking in the late 2040s. Only industries using low- and medium-temperature heat (the pulp and paper, and food and beverage sectors) see lower emissions by 2050, driven by increasing electrification of low-heat processes that benefit from a less carbon-intensive power sector. The cement sector has significant process emissions and no cost-competitive net-zero options. Its carbon emissions rise 27% by 2050, the fastest growth of all industries.

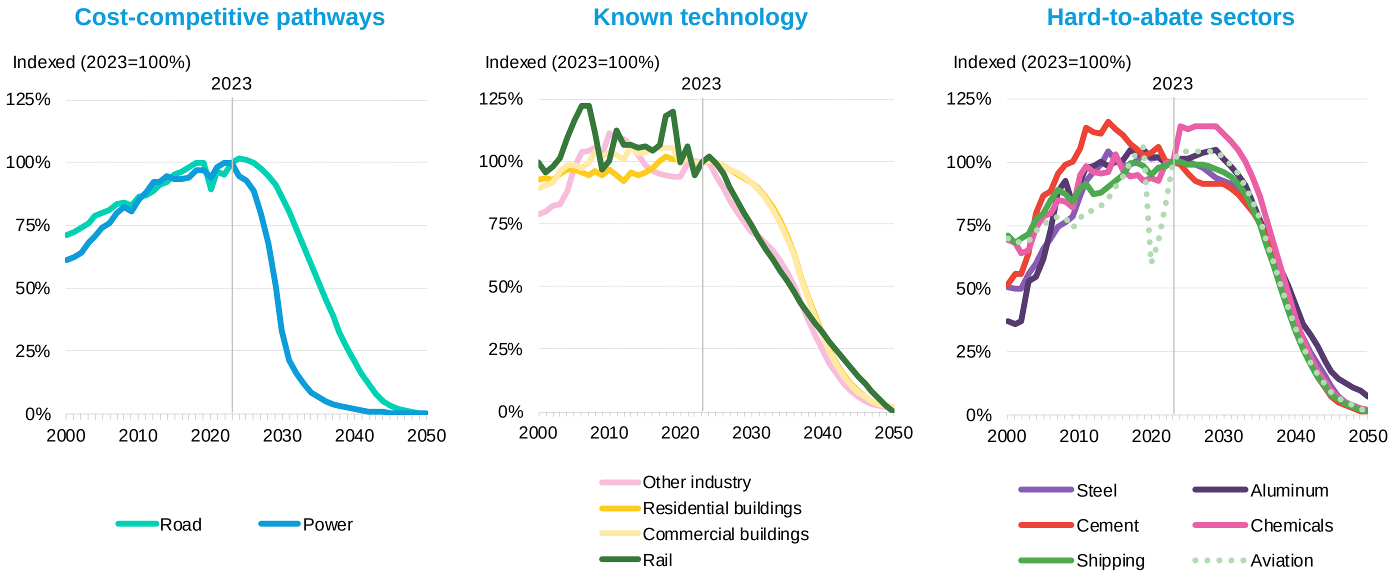
## Net Zero Scenario

Our Net Zero Scenario reveals the sheer scale and scope of the challenge of remaining within 1.75C of global warming and achieving the goals of the Paris Agreement. The window to do so is rapidly closing. Among other things, staying on this trajectory requires:

- An immediate peak and decline in emissions from all sectors starting from this year. Power sector emissions must plunge by 93% by 2035 to create headroom in the carbon budget for other sectors.[2]
- An immediate peak and reduction in use of all three fossil fuels. Oil demand is curtailed by 75% by 2050, coal consumption by nearly two-thirds, and gas use halved.
- A tripling of renewable energy capacity by 2030 to 11 terawatts, followed by another doubling to 2040.
- EVs to account for 100% of new passenger vehicle sales globally from 2034 onwards, with the full on-road fleet going electric by 2046. This implies a 10-year countdown from today until the last internal combustion engine vehicle is sold.
- A rapid increase in carbon capture and storage capacity for power and industry, to 3.9 billion metric tons of CO2 (GtCO2) per year by 2030, rising to 8.1GtCO2 by 2050.
- The full decarbonization and a fourfold expansion of hydrogen production, from 94 million tons of fossil-fuel-based output today, to 390 million tons of clean hydrogen supply by mid-century. This is mainly for use in the industry and transport sectors.

The power and road-transport sectors have the most mature low-carbon technology solutions and need to transition the fastest. In the buildings sector, technology solutions are emerging but are hard to implement. Finally, 'hard-to-abate' sectors such as aviation, shipping and industry – where greener alternatives are currently limited or very expensive – require the most time to reduce emissions.

**Figure 7: Sector and sub-sector carbon budgets, Net Zero Scenario**




*Source: BloombergNEF. Note: Emission trajectories indexed to 2023 values. Aluminum direct emissions in 2050 are near-zero (about 14MtCO2) but show up in the chart as absolute emissions today are already low.*

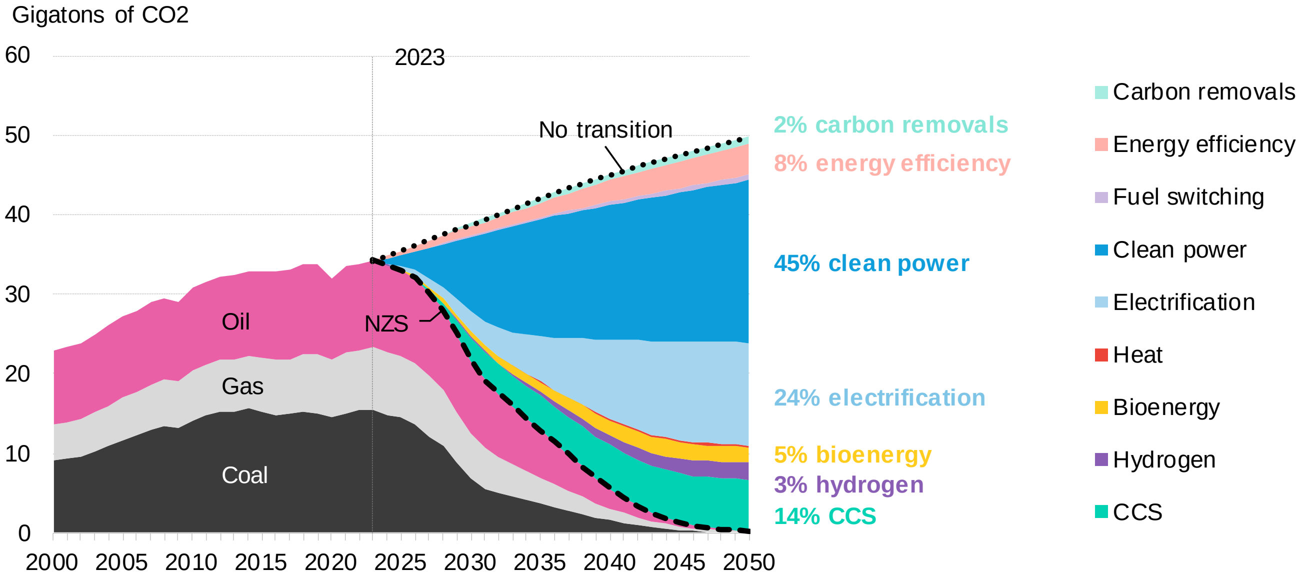
[2] The carbon budget describes the total net amount of CO2 that human activities can still release into the atmosphere while keeping global warming to a specified level, like 1.5C or 1.75C relative to pre-industrial temperatures. BNEF applies sectoral carbon budgets in its net-zero modeling.

## Tough choices await beyond clean power and electrification

Cleaning up the power sector accounts for almost half of emissions avoided between today and 2050, compared with a no-transition scenario where there is no further action on decarbonization (Figure 8). The electrification of end-use sectors, including road transport, buildings and industry, accounts for another quarter.

The solutions needed to abate the final quarter of emissions are the most challenging to scale: biofuels in shipping and aviation; hydrogen in industry and transport; and carbon capture and storage in industry and power.

**Figure 8: CO2 emissions reductions from fuel combustion by measure, Net Zero Scenario versus no transition scenario**

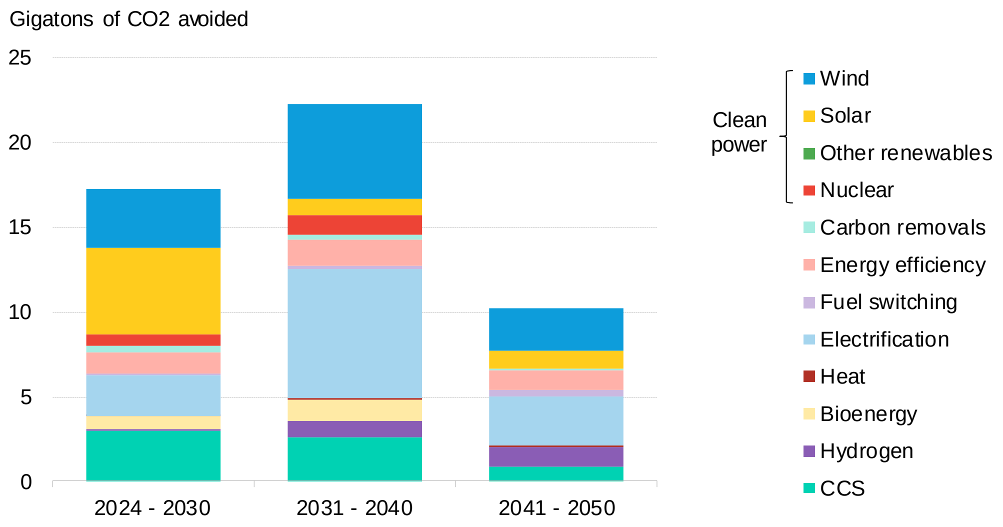



*Source: BloombergNEF. Note: The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes the future fuel mix does not evolve from 2023 (2027 in the shipping sector). For all other sectors, the counterfactual to the Net Zero Scenario (NZS) is the Economic Transition Scenario. 'Clean power' includes renewables and nuclear, and excludes carbon capture and storage (CCS), hydrogen and bioenergy, which are allocated to their respective categories. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry.*

## Progress in the next 10 years is critical

Early emissions reductions are crucial in the NZS. The period 2024-2030 is dominated by rapid power-sector decarbonization, energy efficiency gains and rapid acceleration of carbon capture and storage deployment (Figure 9). Wind and solar alone are responsible for half of emissions abatement during this seven-year period.

**Figure 9: Net CO2 emissions reductions by period and measure/technology, Net Zero Scenario versus no transition scenario**




*Source: BloombergNEF. Note: Data shows the net contribution of each technology to carbon emissions abatement by time period compared to a counterfactual 'no transition' scenario in which there is no further action toward decarbonization. Time period lengths differ. CCS is carbon capture and storage. 'Other renewables' includes all other non-combustible renewable energy in electricity generation, including hydro, geothermal and solar thermal.*

While the deployment of renewables continues across 2031-2040, the focus switches to electrification. Electrifying end uses in industry, transport and buildings account for 35% of the emissions avoided during this period. Abatement from hydrogen and bioenergy also rises in importance as the carbon budgets for hard-to-abate sectors tighten.

The third period from 2041-2050 relies on a mix of different technologies aimed at hard-to-abate sectors, with hydrogen accounting for 11%.

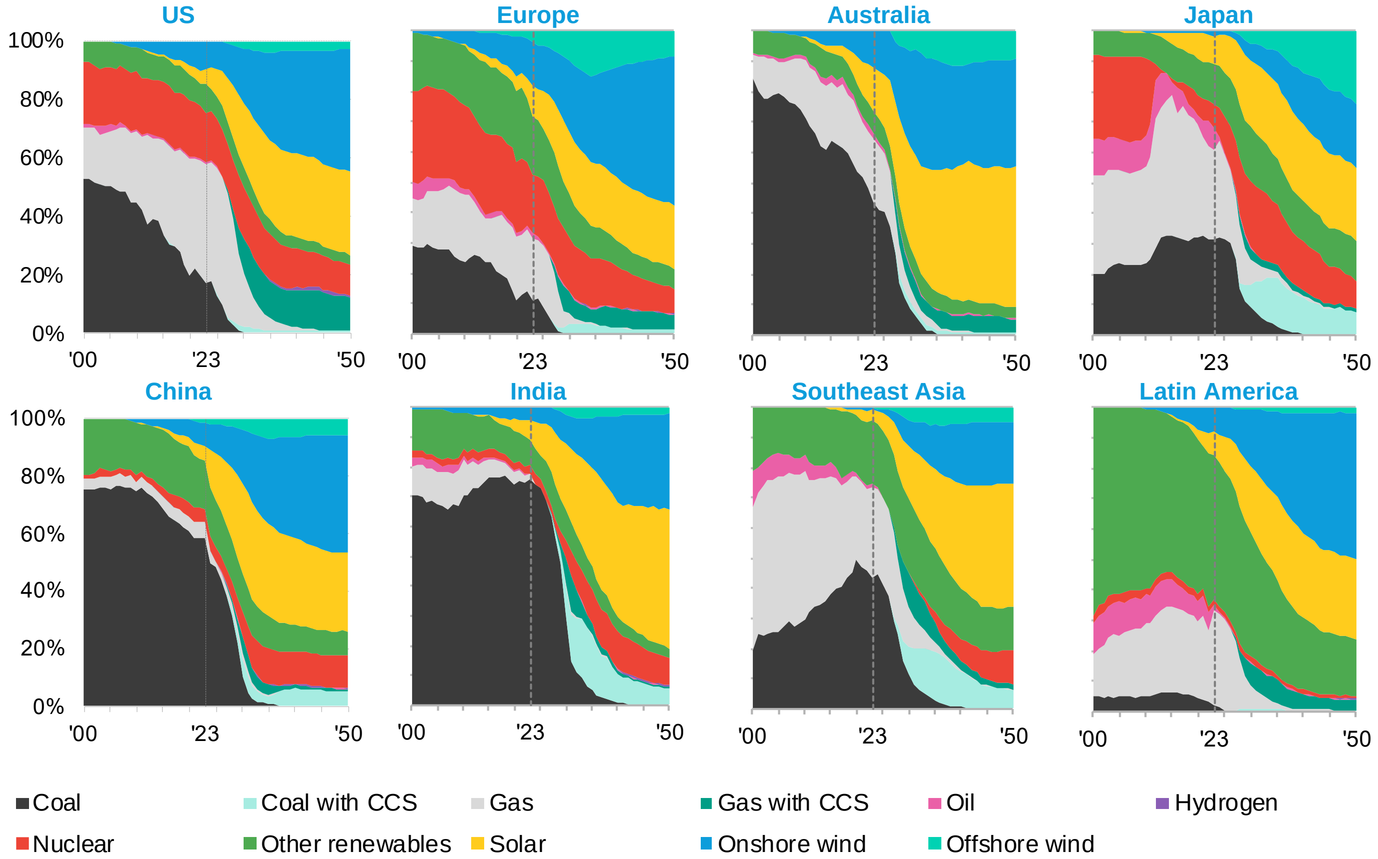
## Renewables dominate the power system, but the technology mix varies with local costs, policy, resources and current energy mix

Renewables dominate power supply in all markets (Figure 10). Their share reaches as high as 95% in Australia and Latin America thanks to excellent sunshine and wind resources. Latin America also benefits from a high contribution from hydropower. Economies with a large legacy nuclear fleet or land constraints have the lowest share of renewables. In South Korea, for example, renewables reach just 63% of electricity supply and in France 67%.

As countries build power plants with carbon capture and storage (CCS), we expect them to run on the fuel that has traditionally dominated the national power mix. In Asia, that is predominantly coal, while in the Americas it is natural gas. In Europe, both are used. In economies that use CCS in the power sector, most combine it with gas in the NZS.

Nuclear plays an important role in several economies' pathway to net zero, including China, India, Southeast Asia, the US, Japan and South Korea. In all these regions, the share of nuclear power grows from 2023, especially in China and India. In Europe, the technology's contribution falls despite further capacity buildout. We do not expect Australia and Latin America to embrace nuclear.

**Figure 10: Electricity generation by source under the Net Zero Scenario, by country/region, 2000-2050**




*Source: BloombergNEF. Note: '00' is 2000, '23' is 2023, '50' is 2050. Includes electricity generation needed for hydrogen production via electrolysis. 'Other renewables' includes all other non-combustible renewable energy in electricity generation, such as hydro, geothermal and solar thermal. CCS is carbon capture and storage*

## Industrial decarbonization unfolds in two distinct phases

The technologies needed to decarbonize steel, cement and chemicals production are still at an early stage. Moreover, diverse solutions are required for these sectors to address asset- and country-specific challenges, and these will take time to scale. There is also a large existing asset base that will not reach its 'natural' retirement age before 2050. The majority of this capacity is in emerging markets and developing economies, placing a disproportionate burden on investment in retrofitting or rebuilding a young asset base.

We see the transition for industrial sectors unfolding in two phases: a first phase of modest emissions reductions based on existing technologies between now and 2030, and a second phase of more aggressive reductions between 2030 and 2050.

- Some decarbonization options can also reduce the production costs of existing capacity, such as fuel switching, improving efficiency and increasing recycling. BNEF analysis shows most materials producers with a net-zero goal are aiming to cut emissions by 30% by 2030 with a combination of these technologies. As well as fuel switching, electrification and bioenergy are some of the most effective levers during this period in the NZS.
- In the second phase, processes using hydrogen and carbon capture should have been demonstrated at scale so that their deployment can accelerate. By 2050, electrification makes

up a third of the total emissions reductions for industry versus a no-transition scenario. CCS is the second-largest contributor, at 27%, with hydrogen and bioenergy making up 15% and 11%, respectively.

## More clarity emerges on choices for shipping and aviation decarbonization

Direct electrification via batteries is the most efficient, cost-effective and commercially viable route to fully decarbonize road transport. Fuel-cell vehicles running on hydrogen play a role in some hard-to-electrify long-haul trucking applications, but do not feature in the larger passenger vehicle market. Synthetic fuels do not arrive at scale in time or at a price point needed to have a material impact.

In aviation, the deployment of next-generation engines and novel airframes lowers final energy demand by 26% compared to the ETS. The use of battery-electric planes after 2030 is restricted to small aircraft flying routes of a few hundred kilometers. Hydrogen-fueled narrowbodies enter the market after 2035 and replace half the jet fuel consumed by conventional narrowbodies by 2050. Despite these innovations, over 70% of final energy demand in 2050 is met by sustainable aviation fuel (SAF). SAF remains the sole option to decarbonize flights using widebody aircraft and other aircraft that cannot use electric or hydrogen propulsion.

Efficiency improvements decrease final energy demand in the shipping sector by 30% in 2050, compared to the ETS. However, low-carbon shipping fuels – including hydrogen-derived fuels such as methanol and ammonia, as well as biofuels – are the only vectors to decarbonize the remaining emissions. The shipping industry is therefore facing the prospect of moving from marine bunker fuels to at least four separate fuels in the next few decades during a transition to net-zero carbon emissions, straining global port and refueling infrastructure.

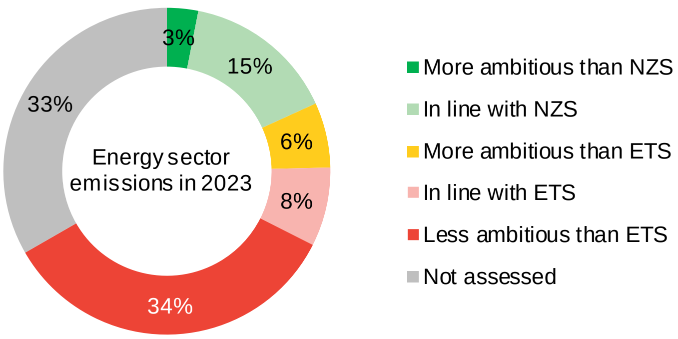
We believe a multi-fuel future is less likely to play out than one with a single clean marine fuel – even though it is hard to specify which fuel will ultimately win out. The adoption of all net-zero marine fuels on offer today is currently miniscule, meaning there is a high degree of uncertainty over the sector’s future direction and fuel of choice.

## Countries can afford to raise their ambitions

BNEF has enhanced its modeling for the 2024 edition of the *New Energy Outlook*. The analysis now includes detailed modeling of 12 countries that account for two-thirds of global energy sector emissions. Examining the Nationally Determined Contributions (NDCs) of these nations – their plans to help achieve the goals of the Paris Agreement – we find:

- The current NDCs of Brazil, France, the UK, the US and Australia are either in line with or more ambitious than the NZS.
- The NDCs of Germany, South Korea, Japan and India are in line with or better than the ETS, indicating they have scope to raise their ambition to align with the NZS.
- China, Indonesia and Vietnam have the most scope to increase their ambition in their next NDCs, with their current plans falling short of even the ETS.

**Figure 11: Level of ambition of Nationally Determined Contributions for the energy sector, by share of global emissions they cover**




*Source: BloombergNEF. Note: Targets adjusted to show energy sector emissions only. Ambition level is assessed by comparing countries' emissions targets (relative to the base year) with modeled results from BNEF's Economic Transition Scenario (ETS) and Net Zero Scenario (NZS). NDC ambition assessments take into account the relative and absolute emissions outcome, crossover points and overall trajectory.*

## Nine technology pillars of a net-zero world

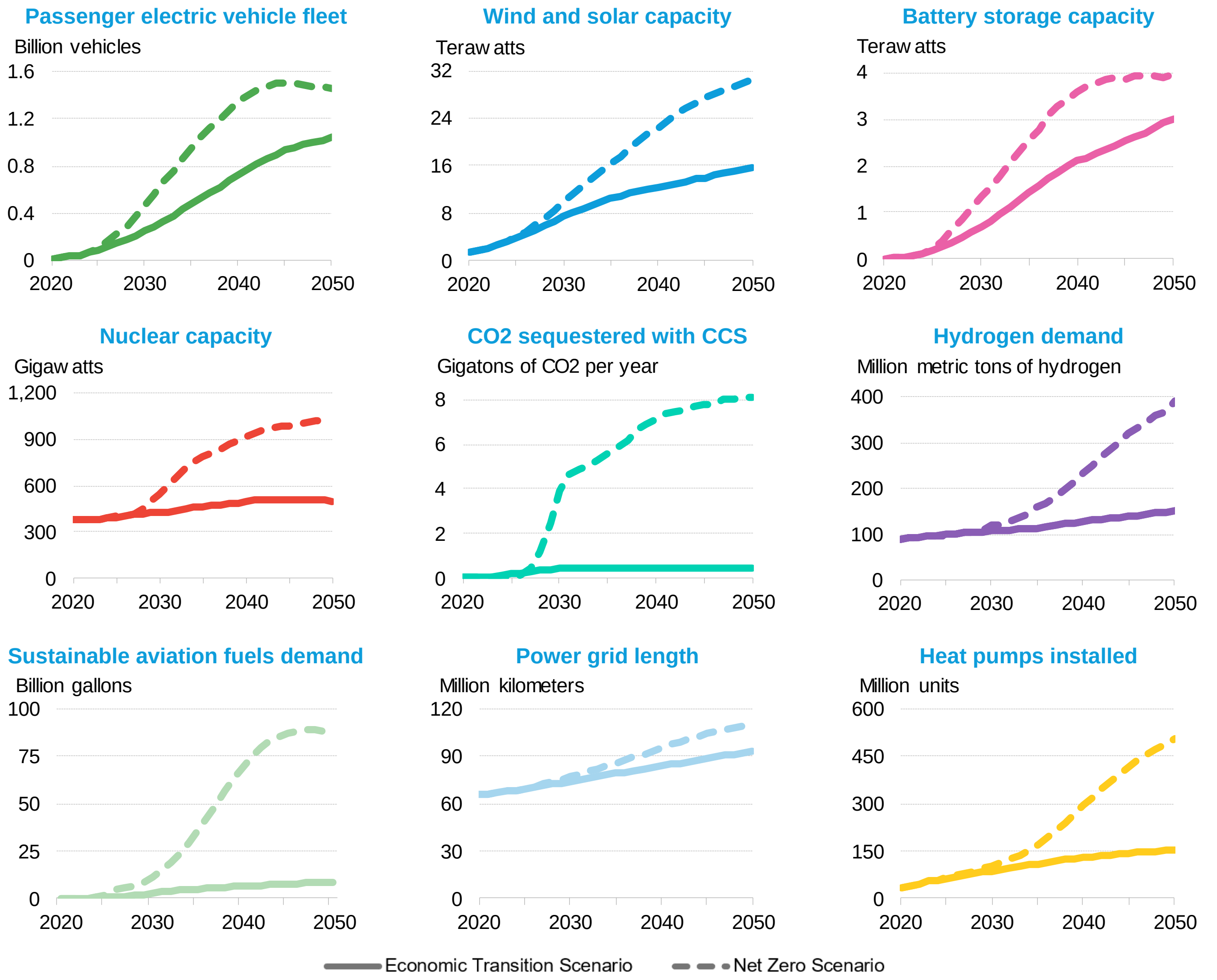
### Nine technologies will make or break the low-carbon transition

There is no single solution that can transform the energy system from high- to low-carbon. Instead, the transition to a net-zero economy will be underpinned by nine technology pillars working in concert to address different elements of the decarbonization challenge. By 2050, our NZS sees:

1. The EV fleet grows to 1.5 billion vehicles and no new internal combustion engine vehicles sold after 2034
2. Wind and solar capacity reaches 31 terawatts (TW) – this sees total renewables capacity triple from today to 2030, and then triple again from 2030 to 2050
3. Installed battery storage capacity hits 4TW – more than 50 times levels in 2023
4. Nuclear power capacity roughly triples to 1TW
5. Carbon capture capacity grows to 8GtCO2 sequestered per year – up from minimal levels today
6. Clean hydrogen use is 390 million tons per year – four times today's fossil-fuel-based hydrogen demand
7. Sustainable aviation fuel consumption hits 88 billion gallons per year – up from minimal levels today
8. The world's power grid grows to 111 million kilometers in length – almost double from today
9. Heat pumps reach over 500 million installed units cumulatively – a near 10-fold increase from today

Among the nine pillars, only four are mature, commercially scalable technologies with proven business models: electric vehicles, renewable power, energy storage and power grids. These still require a significant acceleration to get on track for net zero, but there is little to no technology risk, economic premiums are small or non-existent, and financing models are already at scale. As seen in Figure 12, each of these technologies sees strong growth in the ETS, demonstrating their maturity.

**Figure 12: Select technology drivers in BNEF's scenario modeling**

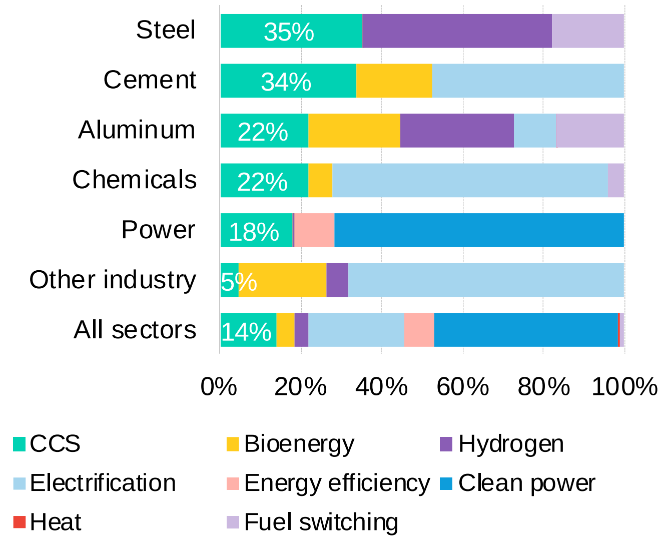



*Source: BloombergNEF. Note: Wind includes offshore and onshore. Solar includes small-scale and utility-scale solar PV. Battery storage includes stationary storage. CCS is carbon capture and storage and the Economic Transition Scenario shows the current project pipeline.*

In contrast, nuclear, CCS, hydrogen, sustainable aviation fuels and heat pumps are not currently cost-competitive or commercially scaling up. As a result, their deployment stagnates in the ETS. But each of these technologies must scale rapidly to achieve the trajectories laid out in the NZS, and each plays a different role in the transition:

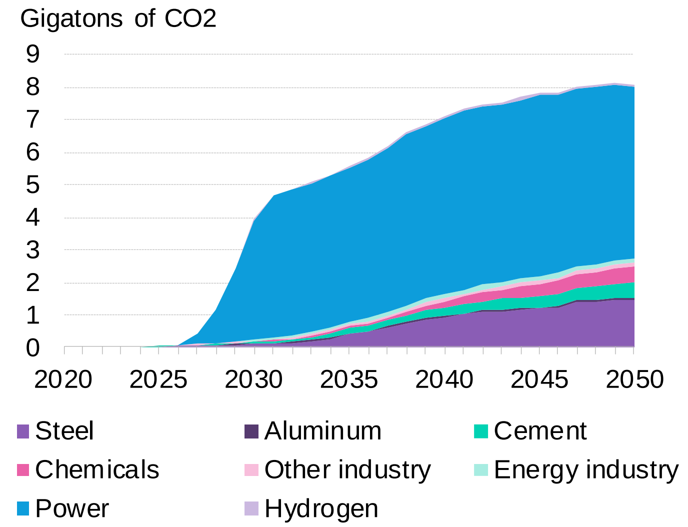
- **Nuclear**: The need for low-carbon dispatchable power under the NZS means nuclear capacity must triple to reach 1 terawatt by 2050. That will require the lifetime of existing plants to be extended, accelerated deployment in mature and fledgling markets, and rapid development of small modular reactors (though these SMRs play a small role due to their higher costs compared to conventional reactors). Nuclear plant additions in the NZS are concentrated in Asia Pacific, accounting for two-thirds of global capacity additions, driven by the need to meet rapidly growing power demand.

**Figure 13: Share of carbon capture and storage in total emissions abatement, 2024-2050, Net Zero Scenario**




*Source: BloombergNEF. Note: Shows cumulative emissions abatement compared with a 'no transition' scenario for energy emissions only; process emissions are not included. Aluminum is primarily recycling and alumina. CCS is carbon capture and storage.*

**Figure 14: Global annual CO2 emissions sequestered by carbon capture and storage, by sector, Net Zero Scenario**



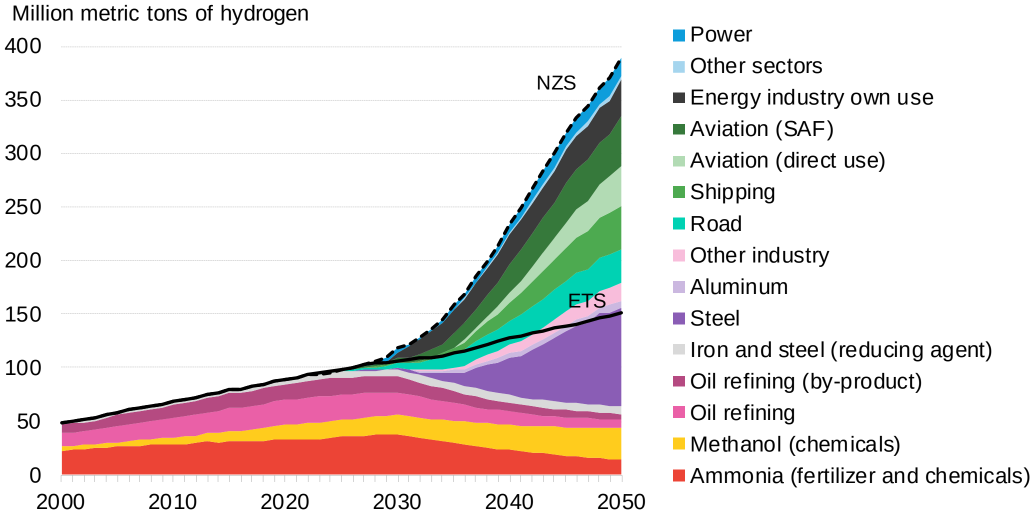

*Source: BloombergNEF*

- **Carbon capture and storage** has broad applications in industry, the power sector and hydrogen production (Figure 13). Between 2024 and 2050, CCS is responsible for 35% of energy emissions abatement in steel production, 34% in the cement sector and 22% in both aluminum production and chemicals processing. 'Blue' hydrogen – made by reforming natural gas and capturing the emissions – accounts for 3% of total hydrogen production in 2050. Fossil fuel-fired power plants fitted with CCS abate 10% of all emissions between now and 2050.
  - A major factor in the large role of CCS in our net-zero pathway is the cost-competitiveness and availability of this technology in the next 10 years relative to other abatement options. Using hydrogen for power generation, for example, is very costly by comparison. To achieve its potential, the CCS industry must reach a threshold it has thus far failed to meet: demonstrate it can reliably capture emissions from these point sources while significantly reducing costs.
  - In the NZS, both carbon capture and storage (sequestering CO2 at the point where it is emitted) and carbon removals (removing CO2 from the air) reduce emissions by a total of 160GtCO2 over 2024-2050. If these emissions were not sequestered, all things being equal, it would put the world on track for 1.9C of warming by 2050. A much faster scaling of other decarbonization technologies, such as hydrogen or bioenergy, would be needed to compensate for the lack of CCS.
- **Hydrogen**: Hydrogen demand in the NZS reaches 390 million tons by 2050, almost a quarter less than in our last outlook but still significant (Figure 15). Three sectors drive the bulk of the growth: steel production, aviation (including both direct hydrogen use and as a hydrocracker

and feedstock in sustainable aviation fuel), and shipping (as methanol or ammonia). Iron and steel manufacturing uses a combined 99 million tons of hydrogen in 2050 – equivalent to 25% of the total in that year and more than the entirety of hydrogen demand today. Aviation accounts for 22% and shipping for 10%.

- Electrolysis becomes the main method of hydrogen production by 2050. To produce the 367 million tons of this low-carbon hydrogen in 2050, close to 3,800 gigawatts of electrolyzer capacity needs to come online. Almost a quarter of all installed wind and solar capacity and just over a fifth of total electricity demand in 2050 is linked to the need to power electrolyzers.

**Figure 15: Global hydrogen demand by sector and application, Net Zero Scenario**




*Source: BloombergNEF. Note: 'Energy industry own use' includes energy consumed to produce final energy carriers from primary energy carriers and energy industry's own use. SAF is sustainable aviation fuel. NZS is Net Zero Scenario; ETS is Economic Transition Scenario. Assumes gravimetric energy density of 140 megajoule per kilogram for hydrogen.*

- **Sustainable aviation fuel (SAF)**: In the NZS, aviation meets its sectoral carbon budget through a combination of aircraft fleet renewals using more fuel-efficient engines and novel airframes, hydrogen-fueled aircraft, and SAF. Compared to a no-transition scenario, sustainable aviation fuel contributes 60% to emissions abatement, followed by energy efficiency measures (28%) and hydrogen (12%). Sustainable aviation fuel is produced mostly from renewable biomass and waste resources and has a lower carbon footprint than conventional jet fuel.
  - Current SAF supply is extremely limited, with just a handful of producers globally, but the industry continues to show promise. The most pressing issue is to diversify production pathways and feedstocks, given the limited availability of feedstocks for current processes. SAF production also requires copious amounts of clean hydrogen for hydrocracking.
- **Heat pumps** play a key role in decarbonizing building heat. In the NZS, cumulative heat pump installations reach 507 million globally by 2050 – more than three times the number installed by that point in the ETS. As the carbon budget for the buildings sector tightens, heat pump adoption accelerates.

# Investment

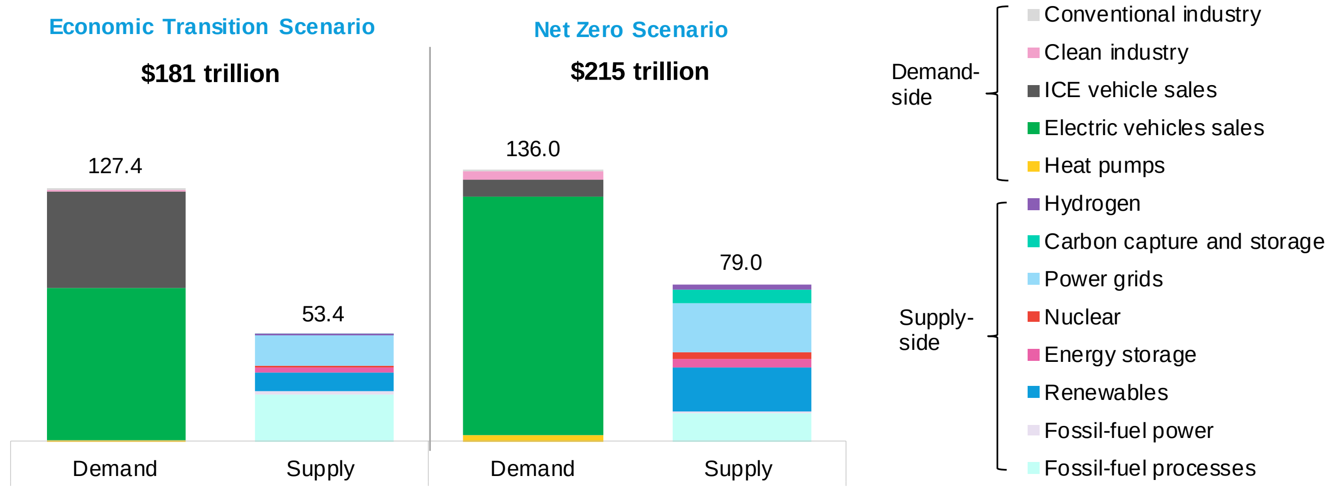
## Investment and spending are only 19% higher in the Net Zero Scenario

In the ETS, companies, financial institutions, governments and consumers invest a total of $181 trillion to 2050 on energy-related infrastructure, technology and products (Figure 16). This is split across $53 trillion for energy supply (both fossil fuels and low-carbon) and $127 trillion for demand-side products (almost entirely for passenger vehicles, both electric and internal combustion engine-based).

Total investment in the Net Zero Scenario is only 19% higher, at $215 trillion. This relatively small difference is because EVs are expected to reach cost-competitiveness with ICE vehicles in the coming years, meaning demand-side spending is only slightly higher than the ETS at $136 trillion.

But supply-side investment is significantly larger at $79 trillion. This is because clean energy technologies are more capital expenditure intensive than traditional energy sources. That said, operating expenditure is excluded from this analysis and would likely be higher for fossil-fuel technologies.

**Figure 16: Global energy investment and spending across 2024-2050, Economic Transition Scenario and Net Zero Scenario**

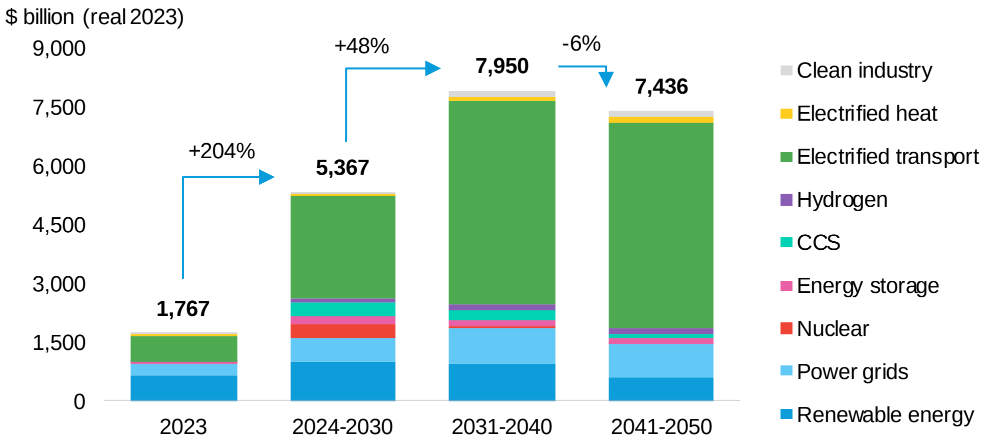



*Source: BloombergNEF. Note: ICE is internal combustion engine. The numbers above the bars indicate cumulative investment and spending figures from 2024 to 2050.*

Today, energy supply investment is spread roughly evenly across fossil fuels and low-carbon sources, at over $1 trillion apiece. Getting on track for the NZS requires a significant step up for clean energy supply and a gradual scaling down for fossil fuels. For every dollar invested in fossil-fuel supply, $4.5 must go to low-carbon energy supply by 2030. The ratio averages just under 3:1 over the rest of this decade, equating to $2.7 trillion of annual investment in clean energy supply and $0.9 trillion in the fossil-fuel side.

Our *Energy Transition Investment Trends* report (link), published earlier this year, concluded that $1.8 trillion was invested in low-carbon energy technologies in 2023. Using the same scope, the NZS requires this figure to rise to an average of $5.4 trillion per year from 2024 to 2030 – a tripling of the current pace of investment (Figure 17).

**Figure 17: Energy transition investment – actuals versus required annualized levels across 2023-2050, Net Zero Scenario**




*Source: BloombergNEF. Note: 2023 shows actuals. Excludes investment in fossil-fuel processes and power and conventional energy, and spending on ICE vehicles, which are not captured in 2023 investment actuals reported in BNEF's Energy Transition Investment Trends report (web | terminal). CCS is carbon capture and storage.*

### The two scenarios see similar totals, but represent fundamentally different choices

The 19% difference between the investment totals in the NZS and ETS is small, and lower operating costs for clean energy could narrow the gap further. But that small gap masks large differences in investment choices, with the NZS representing a breathtaking leap in the speed of clean technology deployments. This underscores the need for stable, long-term policy signals – empowered by strong political will – to divert investment away from fossil-fuel-based pathways and toward low-carbon solutions.

## Land

### Land use will need to be optimized to achieve three goals: enabling the energy transition, meeting growing food demand, and preserving biodiversity

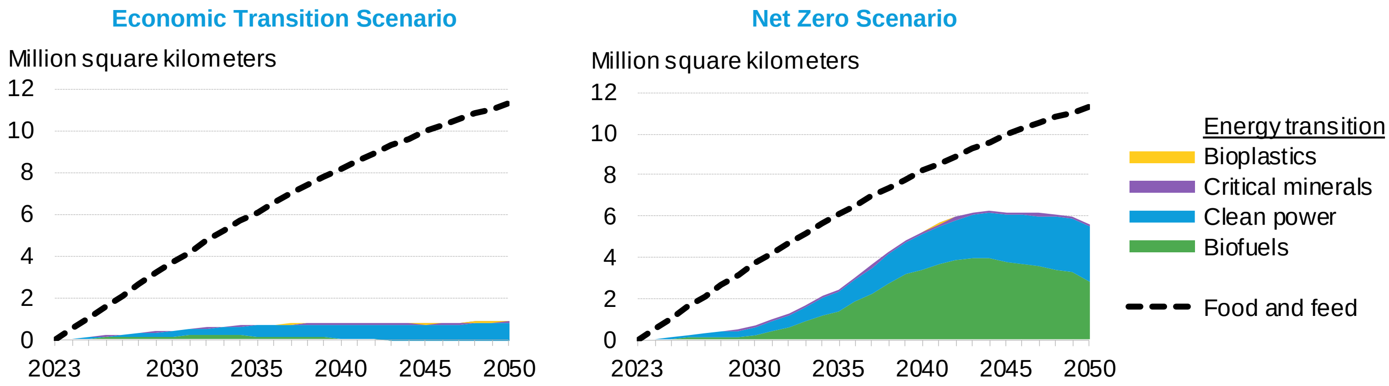
We have enhanced our land-use modeling in the past year, leveraging geospatial data to compare the land requirements of key low-carbon technologies against the availability of suitable land. Across most sectors, low-carbon solutions have a much greater land footprint than the fossil-fuel technologies they displace.

In the Net Zero Scenario, onshore wind and solar projects require 2.9 million square kilometers of land by 2050. That is almost 15 times more than was being used by the two technologies in 2023. At the peak of biofuel demand in 2044, some 4.8 million $km^2$ of land is needed to cultivate feedstock, comparable to the area covered by the European Union. Meanwhile, mines supplying the critical minerals needed for the net-zero pathway span 180,000 $km^2$ by 2041, more than the area of Uruguay. The land requirements of biofuels and critical minerals ease slightly by 2050.

- Land constraints in some countries mean the total land area suitable for solar and wind construction could face saturation in the NZS. South Korea, Vietnam and Japan are most likely to encounter this problem, indicating a greater share of less-land-intensive technologies will be needed in future, such as offshore wind, geothermal or nuclear. Importantly, no countries risk saturation in the ETS, meaning there is still plenty of room for renewables growth in all geographies.

- Land that meets the suitability criteria for solar or wind may also meet those of fuel and food crops. The way in which these segments compete for, and co-exist on, the same land will shape future permitting and zoning rules, particularly if the rollout of low-carbon technologies is seen to threaten food security.
- Growing populations and rising food demand mean we will need far more additional land for agriculture than the energy transition in the NZS. The question is therefore not whether there is enough land for clean energy, but rather how to meet growing land requirements for both food and energy, while also preserving the biodiversity critical for the planet.

**Figure 18: Change in land requirements for agriculture and the energy transition from 2023 levels, ETS and NZS**




*Source: BloombergNEF. Note: Uses the same population, GDP and food demand assumptions in both scenarios. Total land demand comparison is illustrative as demand categories are not necessarily additive.*

- There are numerous measures that can help bridge land-use needs in the coming decades. These include innovations in clean energy assets, such as co-location of renewables with other productive land uses, technological advances that increase energy production for each unit of land, alternative siting choices, and greater inter-regional connections to transmit renewable energy from less-constrained geographies. On the food and agriculture side, double cropping to produce two or more harvests each year from the same parcel of land, reducing food waste, and dietary changes can help reduce pressure on land.

# List of figures in the report

# About us

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|---|---|
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